RESEARCH IN CHINA

IN THREE VOLUMES AND ATLAS

VOLUME ONE IN TWO PARTS

PART ONE

DESCRIPTIVE TOPOGRAPHY AND GEOLOGY

by

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PART I.

Carnegie institution of Wash.

SECTION III.

CENTRAL CHINA.

LIST OF ILLUSTRATIONS.

ERRATA.

Page 88, line 17: for "distant" read "distinct."
Page 94, paragraph 3, line 5: omit the word "other."
Page 99, paragraph 2, line 2: omit the first "g" from "Shang-tung."
Page 161, line 10: for "1,200" read "2,000" and for "350" read "600."
Page 171, paragraph 1, lines 8 and 9: transpose the latitudes and longitudes given.
Page 204, paragraph 2, line 4: for "Mi-chong" read "Mi-ch'ŏng."
Page 210, last paragraph, line 4: for "Li-yüan-p'u" read "Liu-yüan."
Page 238, lines 14 and 21: also in title of Plate XXXII, A, and elsewhere, for "saplite" read "saprolite."
Page 305, paragraph 2, line 7: for "Nu-wang-miau" read "Liu-wang-miau."
Page 312, Plate XL: for "Chiang-k'ou-shĭ" read "Chang-k'óu-shĭ."
Page 317, paragraph 2, line 1: for "subsequent page" read "previous page (295)."
Page 334, paragraph 1, next to last line: for "Huang-yang" read "Huang-ling."

PREFACE.

Baron Ferdinand von Richthofen, by his extensive exploration and penetrating research, laid the foundation for all future geologic work in China. In his journeys from the extreme south to the far north, from the eastern plains to the western ranges of the Empire, he observed all phases of geographic and geologic phenomena presented in that vast area, and grasped the problems broadly and strongly. His early views, published in 1878 and 1882, were developed in accordance with theories which were unchallenged until the last decade of the century, yet as they now stand in "China" they do not always do justice to the advance which he made, keeping abreast of the science. With marked hospitality of mind he welcomed each new fact, received every new view that came fairly accredited, and even though he might not adopt, he courteously entertained them. The plans of the expedition of 1903-04 were laid before him at their inception and were perfected through his advice. After our return the results were discussed with him in Berlin during March, 1905. We are privileged to say that he looked forward with cordial interest to the publication of these volumes, in which his name so often appears, and in earnest search for the truth would have justly reviewed whatever they present of reliable fact or induction. In sincere appreciation of his great contribution to knowledge of Asia, we record our deep indebtedness to him.

The plan of the Carnegie Expedition to China of 1903-04 was conceived by Dr. Charles D. Walcott, whose interest in geological science in general, and in the faunas of the Cambrian period in particular, had led him to a keen appreciation of the possibilities suggested by the results of Baron von Richthofen's explorations. In accordance with Dr. Walcott's purposes, the objects of the expedition were, from the first, purely scientific, yet comprehensive. It was intended that the scope of research should comprise the stratigraphy and paleontology, the structure and physiography of the regions visited, and that the survey should be carried out with as much thoroughness as the local conditions might permit.

The first grant for execution of Mr. Walcott's purpose was made in the autumn of 1902, and Dr. Arthur C. Spencer of the U. S. Geological Survey was charged with the preparation of plans, in the expectation that he would carry them out. Later, when Mr. Spencer was obliged to forego the opportunity, I volunteered for the service and the expedition was intrusted to me. Mr. Eliot Blackwelder of the University of Chicago was chosen as associate geologist, and Mr. R. Harvey Sargent of the U. S.

Geological Survey was asked to join us in China as topographer of the expedition, in case it should be found that we could avail ourselves of his services.

In July, 1903, Mr. Blackwelder and I sailed for Europe, and after conference with scientists abroad, went by the Siberian railroad to Peking, where we arrived late in September. The Chinese authorities, already advised of the scientific purpose of the expedition, courteously accorded us every facility, and early in October we proceeded to the province of Shan-tung, where the remainder of the autumn was spent in detailed geologic studies of two selected areas, and in general observations en route from Tsi-nan-fu to Tsing-tau. We returned to Tientsin December 11, and after brief preparation Mr. Blackwelder left, with a single Chinese companion, for Liau-tung, where he conducted a reconnaissance in the peninsula north of Port Arthur.

With Mr. Sargent, who had joined us, I remained at Tientsin making preparations for the journey to central China, which had been determined upon after consideration of several alternative plans. During the Christmas week, in response to a request of the American Minister, Hon. E. H. Conger, I made a study of and report on the artesian water conditions of Peking.

The journey to central China and thence to Shanghai occupied the first five and a half months of 1904. Our route was so chosen as to avoid, over long distances, that pursued by von Richthofen, and yet was so related to his that a comparison and checking of observations was practicable. From Pau-ting-fu in the province of Chï-li we went westward 150 miles to the Wu-t'ai-shan, the highest range in northern Shan-si, and thence southward 100 miles to the old city of T'ai-yüan-fu, where we arrived early in March, having spent two winter months in the bleak and inhospitable mountains. The cold was, however, never very severe, as the thermometer did not fall below zero Fahrenheit; there was but little snow, and the weather was generally favorable for topographic and geologic work, except for occasional dust storms, which clouded the atmosphere.

From T'ai-yüan-fu, Shan-si, to Si-an-fu, Shen-si, we had hoped to proceed by an indirect route, which should include a survey of the Huang-ho in its long course from north to south between the two provinces, but it became evident that such an undertaking would delay us till the months before the beginning of the rainy season in central China had elapsed; and in a choice between the two sections the advantage seemed to lie with southern Shen-si. Accordingly we proceeded as rapidly as possible, via the great highway from T'ai-yüan-fu to Si-an-fu, and reached the latter city on the 1st of April.

We proposed to continue our journey from Si-an-fu to the Yang-tzï by some route not previously surveyed. It chanced that just at that

season a British expedition under Colonel C. E. Manifold and a German one under Lieutenant Filchner were engaged in exploration in southern Shen-si, and to avoid duplicating their observations we took our way further to the west than we had intended. We crossed the Ts'in-ling-shan from Chóu-chï-hién to Shï-ts'üan-hién, a distance of 100 miles, by a route not previously traveled by any foreigner, and from 30 to 50 miles east of von Richthofen's. From Shï-ts'üan-hién we proposed to continue southward to Wan-hién on the Yang-tzï, but were advised to avoid the particular mountainous district which lay between, as the famine which then prevailed in parts of southern Shen-si was especially severe in the remote and inaccessible districts through which the by-paths led. We therefore went by boat a hundred miles down the Han river to Hing-an-fu, whence we took a more commonly traveled path for 175 miles across the mountains, via P'ing-li-hién, to Wu-shan-hién at the head of the Yang-tzï gorges. In so doing we unintentionally struck a route surveyed but a few weeks before by Colonel Manifold and his associates.

Having been delayed at Si-an-fu by continuous rain, we did not start across the Ts'in-ling-shan until the 21st of April. Shï-ts'üan-hién was reached May 10, and Hing-an-fu May 14. We left Hing-an-fu on the 17th and arrived at Wu-shan-hién June 6. Thence it was three days' trip by boat to I-chang, where the journey of investigation came to an end.

The geographical and geological observations of the expedition are embodied in this volume, which is divided into two parts. Part I contains the statement of detailed facts arranged according to regions and subordinately according to geological periods. Part II comprises systematic petrography and zoological notes by Mr. Blackwelder and a syllabary of Chinese sounds by Professor Hirth.

In a second volume I propose to summarize the detailed presentation of our results and to combine them with the work of others in a systematic discussion of the geology of southeastern Asia. The fossils which were collected have been studied by Dr. Charles D. Walcott, Professor Stuart Weller, and Dr. George H. Girty, and are described and discussed by them in Volume III, which is devoted to Paleontology. The atlas contains Mr. Sargent's contribution and also the geologic maps.

This first volume is the joint work of my associates, Eliot Blackwelder, R. Harvey Sargent, and myself. Each chapter is credited to the one who, in accordance with the plan agreed upon, wrote on that particular subject, but no chapter is exclusively the independent work of any one of us. Mr. Blackwelder is chiefly responsible for stratigraphic details, and Chapter XVI, on petrography, is peculiarly his own work. The chapter on topographic methods is more particularly Mr. Sargent's contribution. I am responsible for the chapters on the loess and physiography. But, in preparing those on geology, Mr. Blackwelder and I have mutually

used each other's notes, reviewed each other's manuscript, and freely discussed all mooted points with a view to welding our statements into a consistent whole.

In the course of the research I have come under obligations to many persons who, in official or personal relations, aided the expedition.

Secretary Hay and representatives of the United States abroad gave valuable assistance, and the Hon. E. H. Conger, minister to China, especially facilitated the establishment of satisfactory relations with the imperial authorities. The ministers at Washington, of England, France, Germany, and Russia, courteously advised their governments of the disinterested purpose of the expedition, and we were officially accredited to the representatives of the respective governments at Peking.

Sir Chen-tung Liang-cheng, Chinese minister to Washington, not only gave aid officially, but personally interested himself in making the work, in part at least, available to the Chinese in their own language. The characters on the maps were prepared under his direction and the description in Chinese, which accompanies the atlas, was written by him.

In China His Excellency the Viceroy of Chï-li, and the Governors of Shan-tung, Shan-si, and Shen-si forwarded our purposes, and many of the magistrates through whose jurisdiction we journeyed gave us material assistance.

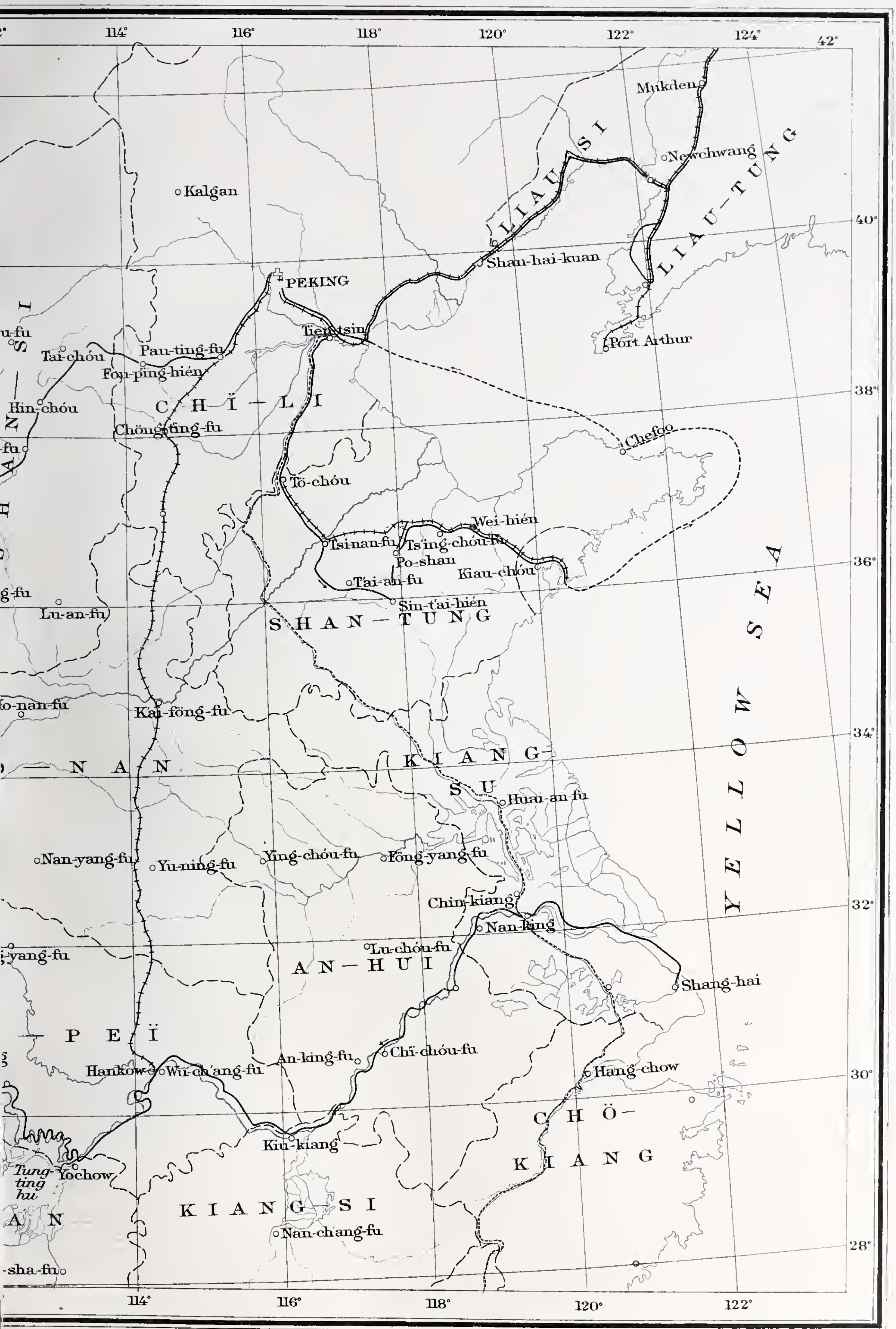
Professor Friedrich Hirth of Columbia University has kindly superintended all matters pertaining to the correct translation and transliteration of the Chinese names. Only one who has attempted to catch the sounds of such names in the different dialects, or who, through familiarity with the Chinese language, appreciates the many meanings which one sound may have, can realize how great is the difficulty of ascertaining the correct names of geographic features. By means of the Chinese gazetteers and maps, made available to us through Professor Hirth's extensive knowledge of the language and literature, and through his personal consideration of the data submitted to him, we have been able to avoid many errors into which we would otherwise have fallen. Professor Hirth has also gone to the labor of transliterating all the Chinese names in a spelling which most nearly expresses the correct pronunciation. The system is fully explained in the Syllabary which he has contributed to this volume and to which the reader is referred.

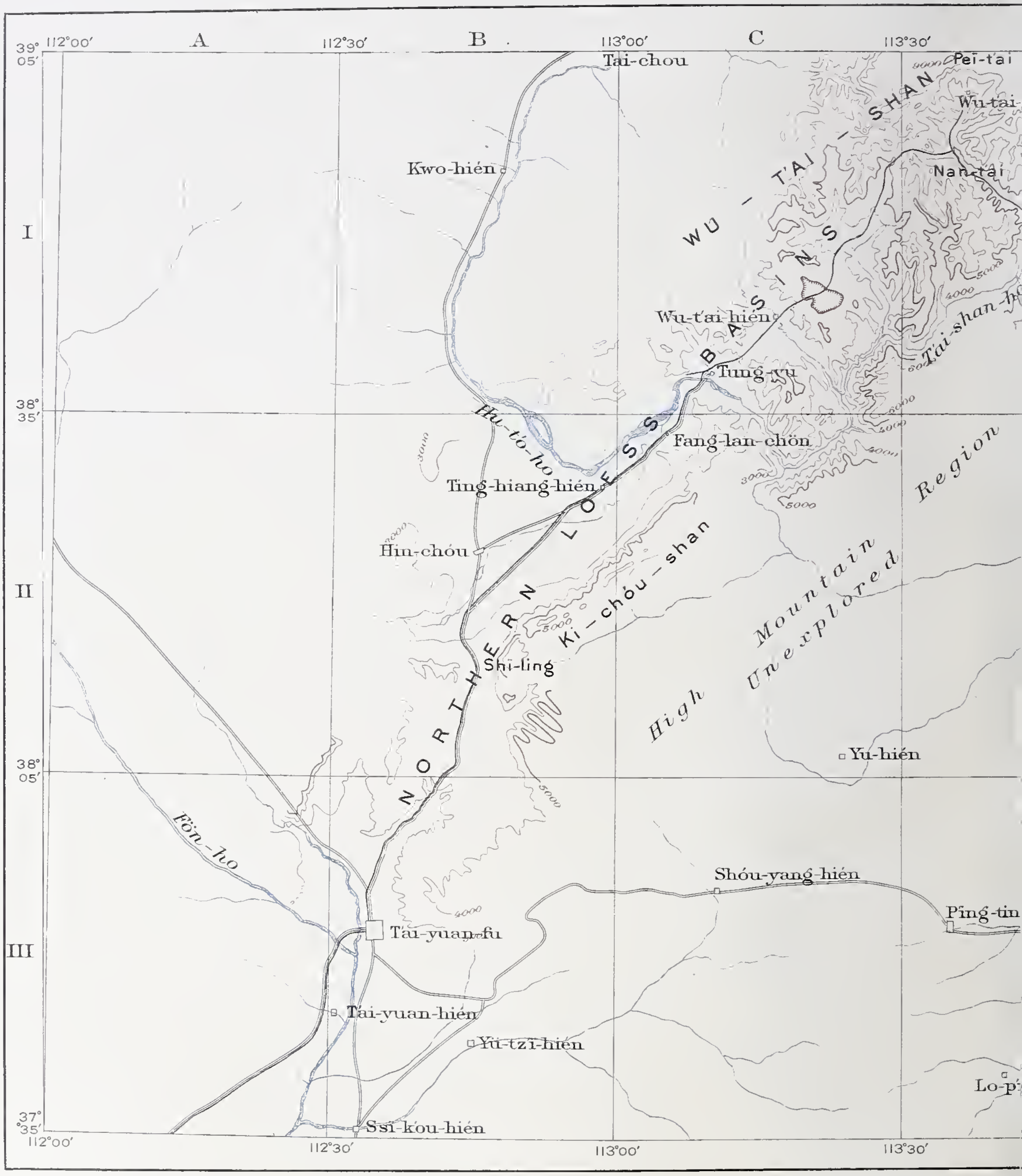
To many colleagues in science, abroad as well as at home, to numbers of friends, American, European, and Asiatic, and to my comrades who made this work possible, including our interpreter Li-san, more acknowledgment is due than can here be expressed.

BAILEY WILLIS.

WASHINGTON, D. C., *March* 28, 1906.


Scale 1:7500000
50 0 50 100 150 200 250 Miles
100 0 100 200 300 Kilometers
= Route of Carnegie Expedition 1903-04.
Route and Index Map.
100° 102° 104° 106° 108° 110°
42° 40° 38° 36° 34° 32° 30° 28°
M O N G O L I A
Ning-hia
Ku-ku-nor
T I B E T
Lan-chou-fu
K A N — S U
Yen-an-fu
Han chong hién
Tung-chóu-fu
Pu-chóu-fu
Huang-ho
Tung-kuan-h
Si-an-fu
Chóu-chï-hién
S H E N S I
Fön-chóu-fu
T'ai-yu
Han-chung-fu
Ssi-ch'uan-hién
Hing-an-fu
Ping-li-hién
Pau-ning-fu
Sui-ting-fu
S S Ï — C H' U A N
Kui-chou-fu
Wu-shan-hién
Wan-hién
Ch'öng-tu-fu
Shun-king-fu
Shï-nan-fu
Chung-king
Ch'ang-tö-fu
K'U I — C H O U
102° 104° 106° 108° 110°


Mukden
Newchwang
LIAU-SI
LIAU-TUNG
Kalgan
Shan-hai-kuan
PEKING
Tientsin
Port Arthur
Pau-ting-fu
Tai-chóu
Fou-ping-hién
Hin-chóu
CHÏ-LI
Chöng-ting-fu
Chefoo
Tö-chóu
Wei-hién
Tsi-nan-fu
Ts'ing-chóu-fu
Po-shan
Kiau-chóu
Tai-an-fu
Sin-t'ai-hién
Lu-an-fu
SHAN-TUNG
YELLOW SEA
Kai-föng-fu
KIANG-SU
Huai-an-fu
Nan-yang-fu
Yu-ning-fu
Ying-chóu-fu
Föng-yang-fu
Chin-kiang
Nan-king
Lu-chóu-fu
AN-HUI
Shang-hai
An-king-fu
Chï-chóu-fu
Hankow
Wu-ch'ang-fu
Hang-chow
CHÖ-KIANG
Kiu-kiang
Tung-ting hu
Yochow
KIANG-SI
Nan-chang-fu
114°
116°
118°
120°
122°
124°
42°
40°
38°
36°
34°
32°
30°
28°



SURVEYS FROM

TO T'AI-YU

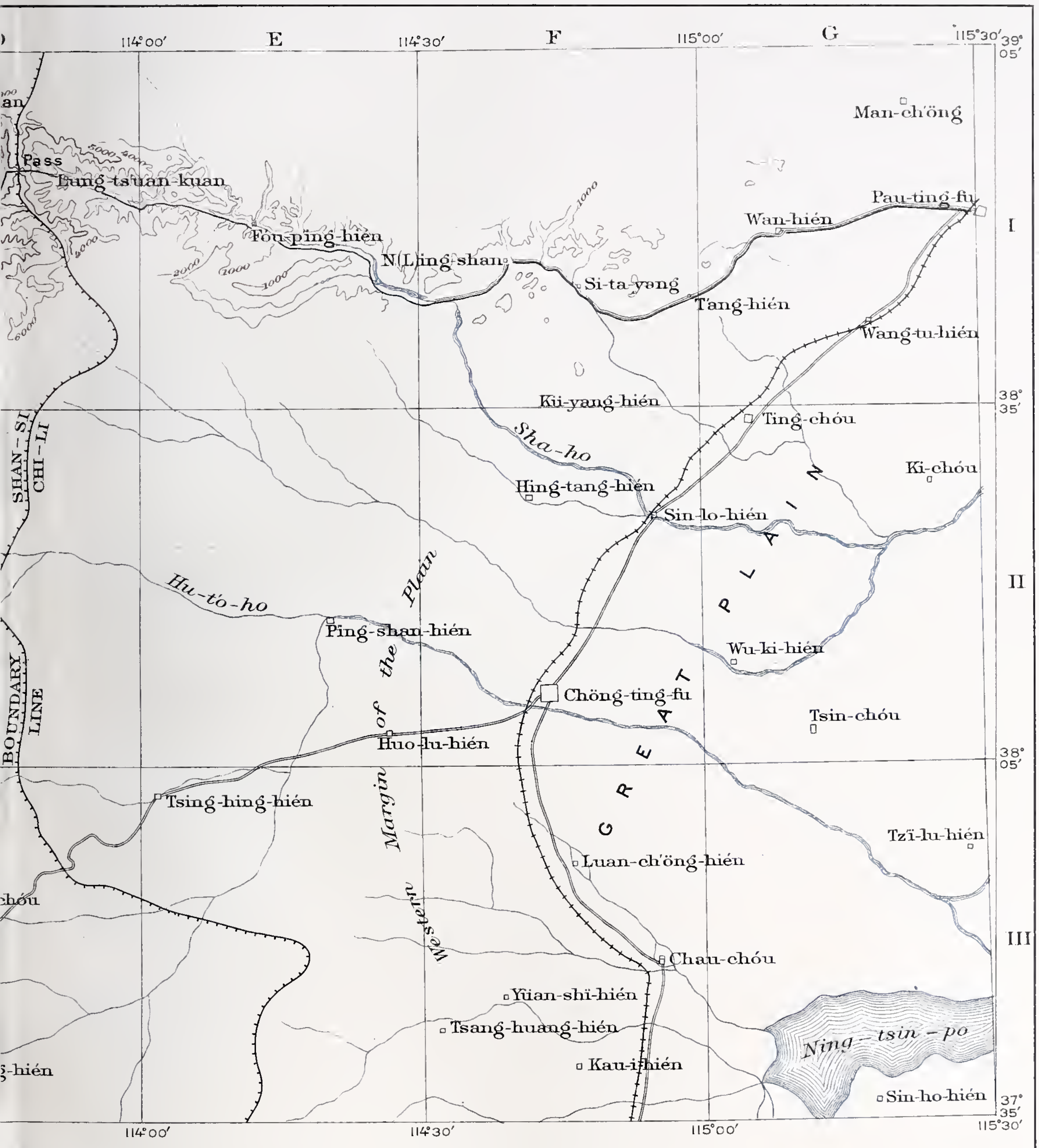
SHEETS

Scale

10 5 0 10

10 5 0 10

ROUTE —— JANU



PAU-TING-FU, CHÏ-LI

N-FU, SHAN-SI

I TO A III

:1000000

20 30 40 Miles

20 30 40 50 Kilometers

AND FEBRUARY 1904

RESEARCH IN CHINA.

A

B

A. Fóu-p'ing-hién, Chï-li. View of bad lands north of the Sha-ho, atlas sheet E I, looking northeast from the peak east of the city; showing effects of denudation in gneissic rocks, aided by recent deforestation.

B. Near Pa-li-kuan, Shen-si, atlas sheet c 5. View in valley of P'ing-li river, illustrating development of features in schists of the Han region, and conditions of rice culture.

CHAPTER I.

TOPOGRAPHIC SURVEYS.

By R. H. Sargent.

INTRODUCTION.

Topographic surveys were undertaken by the Carnegie Expedition to China for the purpose of producing base maps, which should exhibit the features of the country in a reliable manner and on a large scale, and which might be used to illustrate detailed geological studies. It was proposed that there should be made a contour map, controlled by triangulation and checked by astronomical observations; the contours to be based on accurate determinations of altitudes and to be drawn to represent expressively the actual forms of topographic features. So far as was practicable under the conditions of our work in China, these requirements were met. In certain districts, however, triangulation was not possible, and it became necessary to resort to stadia surveying; and in the canyons of Shen-si the view was limited to the route traversed. The conditions under which the surveys were executed, and the checks which were secured on the accuracy of the work are more fully explained in the following paragraphs. Inspection of the atlas accompanying the report will best show the results obtained.

Two small areas were surveyed in Shan-tung, during the autumn, by Mr. Willis before the topographer joined the party. They are represented in the Ch'ang-hia and Sin-t'ai sheets, Plates XIII and XIV of this volume. The major part of the surveys falls into two widely separated sections. The one, comprising the first ten atlas sheets, extends from Pau-ting-fu in the province of Chï-li to T'ai-yüan-fu, Shan-si. (Plate II.) The second section, which is delineated in the ten remaining atlas sheets, extends from Chóu-chï-hién, Shen-si, to Wu-shan-hién, Ssï-ch'uan. (Plates VI and VII.)

During the initial work at Pau-ting-fu I was fortunate in having the assistance of Captain Turner, detailed from the force of the British Intelligence Bureau, North China Command, by Colonel A. W. S. Wingate. By order of Colonel Wingate, a Hindoo sergeant, Abdullah, trained in the British method of military reconnaissance surveying, accompanied us and

carried a route survey as far as Si-ta-yang. Recently arrived from India, he was unable to stand the rigors of January in North China, and becoming ill was sent back to Tientsin. The geologists, Messrs. Willis and Blackwelder, from time to time executed route surveys, usually with compass and pacing, occasionally with plane-table and stadia. These have been adjusted to the topographic control and incorporated in the details of the maps. The topographer is alone responsible for the astronomical observations, the results of triangulation, and the delineation of features by contours.

I was dependent entirely upon native assistants, who in the beginning were ignorant of the services required, and with whom I could communicate only through their slight knowledge of English. Two of our Chinese servants aided more or less in the work and one of them, Siau-ïr-ko, a man of unusual strength and energy, generally accompanied me. He quickly grasped the routine of setting up the instruments on stations and the manipulation of the stadia rod. Though a native of the plains, he became a fearless and skilful mountain climber. He was untiring and loyal and his services were of high value.

The instruments employed in the work were a theodolite, a sextant with artificial horizon, telescopic alidades, plane-tables, box and prismatic compasses, and aneroid barometers. The theodolite, which was loaned by the British Intelligence Bureau through the interest of Colonel Wingate, was of English make. The objective was one inch in diameter, with a focal length of 8 inches. The horizontal and vertical arcs were 5 inches and $4\frac{1}{2}$ inches in diameter, respectively, and each vernier was graduated to the nearest 15 seconds. The vertical arc and its level were attached to the axis of the telescope, which, when not in use, was lifted from the Ys and packed separately from the base. The Ys were of sufficient length to permit transiting the telescope without lifting it from them. The sextant did not differ materially from those in general use, except that it was much heavier in construction. Its vernier read to the nearest 10 seconds. The alidades, plane-tables, and tripods were loaned by the United States Geological Survey, and were of the types regularly in use in operations in the United States. They are fully described in the Manual of Topographic Surveying by H. M. Wilson.* The stadia rod was made up of painted aluminum plates, each one foot in length, which were carried separately and attached to a board or pole when needed.

The methods of the survey were adapted to the character of the country, the conditions of atmosphere, and the rate of progress required by the

* Chapter VII, Article 56.

extent of the journey. The essential object, an adequate and expressive contour map, was not lost sight of, but economy of time and extension of the work over the largest possible area were requirements constantly imposed. A method of graphic triangulation with the plane-table was adopted as the most satisfactory, wherever conditions permitted its use. By this method triangulation is expanded from a measured base line by sights taken with a telescopic alidade and recorded simply by a pencil line drawn upon the precisely oriented plane-table sheet. The intersection of three or more fine lines in a single point is taken to indicate the position of the object sighted, within the limits of the scale of the map. The method and the results which may be attained by it are fully described in the manual already referred to.* Vertical angles are measured with the telescopic alidade, and from these differences of elevation are calculated. The altitudes of all primary points are determined as the average of numerous observations from as many different stations. Those of minor features which are required for controlling contours are calculated at once on the station from the observed angle and known distance, and the contours are indicated on the sheet in their proper positions. In doing this, care is taken to draw them so that they shall express the form of the observed feature, whether angular or rounded, precipitous or gently sloping, and thus convey a correct impression of the character of the surface. In such rapid work as was executed in China it was not usually possible to connect up all the contours and complete the map in the field. The final drawing was made in the office after our return, on the basis of the features sketched in the field and with the aid of numerous photographs.

As already stated, graphic triangulation was not always practicable, and we resorted to stadia surveys. The methods and precautions used in this class of the work are set forth in connection with the sections thus surveyed.

The description of the surveys which follows falls into several sections according to the districts, the conditions, and the methods. The nature of the country passed through is illustrated in the plates accompanying this chapter, which are especially selected to show the very distinct types of hill and mountain, valley and canyon of North and South China, and the wide difference between the treeless districts of the north and the wooded region of the south.

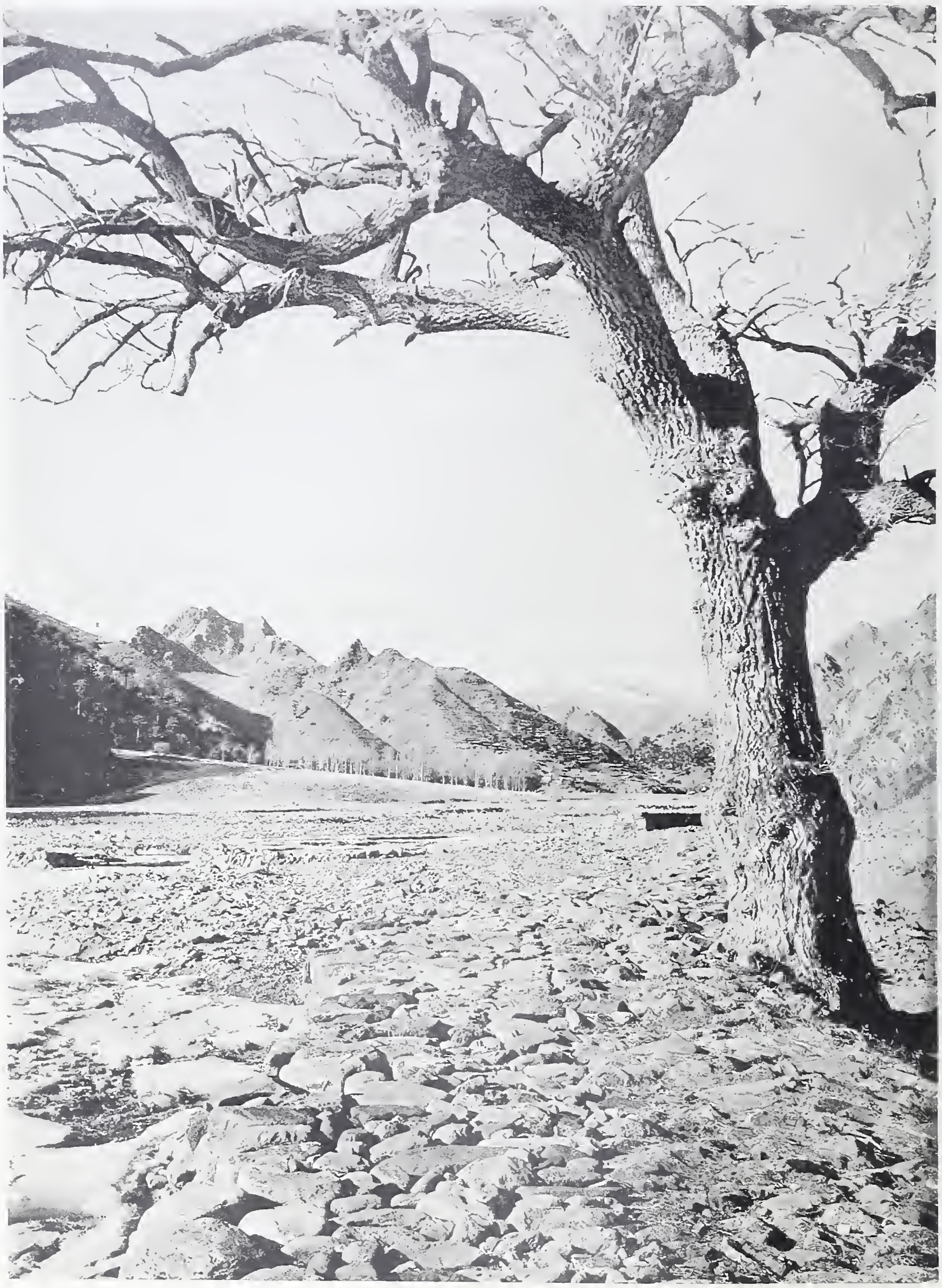
* Chapter VII, Article 54 and Chapter IX, Article 74

SURVEYS IN CHÏ-LI AND SHAN-SI.

PAU-TING-FU TO T'ANG-HIÉN.

Stadia Traverse.—The city of Pau-ting-fu, south of Peking, is on the line of the Belgian railway, and the position of its northern gate tower has been determined astronomically by the British Intelligence force as being lat. 38° 51′ 26″, long. 115° 30′ 53″. We were thus able to obtain an adequate datum for elevation and a fixed point from which to start the survey. A base line was measured on the railroad and the attempt was made to expand from it, with the theodolite, to prominent points in the foothills on the western side of the Great Plain. Although the distance is probably not more than 25 or 30 kilometers we could not see the heights on account of the dust in the atmosphere, and our hopes that the air might clear were not likely to be realized for two or three months, so the natives said. Finding it impossible to see more than 5 to 8 kilometers across the dead level of the featureless plain, and being obliged to proceed at once, we were forced to give up the initial idea of triangulation from Pau-ting-fu and to adopt a stadia survey until we should come within sight of the hills or into a clearer atmosphere.

Special precautions were taken in running this stadia traverse, as it was considered an element of the continuous system, which was to be extended from Pau-ting-fu to T'ai-yüan-fu and was to be the check for longitude between these two points. In order that the alinement or direction might be platted with precision, the line was run with fore and back sights and was furthermore oriented with reference to a sharply defined distant object. With the table in the first position an object some 2 or 3 miles ahead was chosen, toward which the line was run. The rod was sent ahead and lined in exactly with this distant object; the length of the sight was then read from the stadia rod and the difference of elevation taken, and then the table was moved to the point occupied by the rod. Here the table was again oriented by the distant object and checked by a back flag which was at the station just left. In this way the line was run as far as possible precisely in one course. When a change became necessary a new distant bearing was selected and the line run straight toward it until another direction had to be pursued. In order to check the distances read and the platting on the sheet, a number of objects on the side were intersected from four or five stations. As an additional check on the platting, every mile or so the sum of the reading was compared with the distance platted. Great care was taken with the levels as well as with the distances, the length of the sights being reduced to 400 and 500 feet during the heat of the day, when the air became unsteady.



Shang-ho-miau on the T'ai-shan-ho, Shan-si. View looking up river to summit of Si-t'ai, one of the heights of Wu-t'ai-shan. View illustrates dome-like character of Wu-t'ai summits, acuteness of lower peaks, and aggraded condition of the canyon; beyond the main river is an immense alluvial cone recently built up by a small tributary.

Liu-yüé-ho, Ts'in-ling-shan, Shen-si, atlas sheet a 2. View in Ts'in-ling mountains at an altitude of about 1,500 feet above the canyon bottom, showing abrupt slopes carved in Pre-Cambrian schists, in strong contrast to flatter profiles at higher levels.

This traverse was commenced from the north gate of the wall at Pau-ting-fu, and was run to the base of a pagoda on a small isolated hill about 11 kilometers east of T'ang-hién and 40 kilometers from the starting point. It is probable that the error in distance will not exceed 350 meters and the level should be within 3 meters. The number of stations occupied was 173 and the average length of the shots was 226 meters. The survey was executed during four consecutive days, from January 3 to 6.

T'ANG-HIÉN TO T'AI-YÜAN-FU.

Graphic Triangulation.—T'ang-hién lies near the western margin of the Great Plain, in the immediate vicinity of low foothills of the mountains which extend from the province of Shan-si into that of Chï-li. Our route lay due west across these mountains to Wu-t'ai-shan, and thence southward among the ranges to T'ai-yüan-fu. Although the conditions of the atmosphere made it impracticable to execute that larger triangulation which we had hoped to carry out with a theodolite as a primary control for the graphic triangulation, we nevertheless deemed it expedient to begin the latter.

A base line about 3 kilometers in length was measured with the steel tape on the plain west of T'ang-hién. One end was established on the northwest corner of the city wall and the other was marked by a temporary signal. The exact position is indicated on the map, sheet F I. With the aid of Chinese assistants two measurements were made which checked within .85 meters. Since this line was to be platted on the plane-table sheet on a scale of 1:90000, the difference between these two results was not measurable on the map and the distance was accepted as sufficiently accurate. Signals were built on several neighboring heights, appropriately chosen to give good triangles, and the graphic triangulation was begun by occupying the base stations and these neighboring points. The network of triangulation can be traced on the atlas sheets, the exact points occupied as stations being indicated by a small triangle.

Had it been practicable it would have been desirable to build monuments upon the triangulation points in advance, in order to give definite objects on which sights might be taken, but we frequently were unable to learn, even from the natives, the exact direction in which we were to travel for a few miles ahead, and there was no one available who sufficiently understood the objects of the work to be sent ahead to construct monuments. Moreover, it had been the experience of Mr. Willis in Shan-tung that monuments which had been erected at a station in order to mark the exact point that had been occupied, had been thrown down over

night. We were therefore obliged to accept sights to more or less sharply defined mountain summits. The uncertainty of our direction and the possibility that one or another sighted peak might not be accessible from our line of march made it desirable to have a number of possible triangulation stations located in advance. It was not, however, always possible to have as many intersections as we might like on the point that we were ultimately obliged to occupy, and the method of locating the triangulation points was by resection. By this method at least one sight from an established point to the point to be occupied was necessary. This sight was drawn on the plane-table sheet while at a previous station, and when the table was set up at the indeterminate station the alidade was placed precisely along the pencil line and sighted back to the station from which the line was drawn. The table being thus very nearly oriented, sights were taken to a number of other established points, and the orientation was adjusted until a sufficient number of lines passed precisely through a point which must lie on the initial line of foresight. It was then accepted as the location of a new station. So far as possible, only stations which had been occupied were used to determine the position of a new station, but conspicuous peaks on either side of the belt of survey were carefully located, and when their position had been fixed by the intersection of four or more lines they were used as checks, and in one or two instances to locate a station. The difficulties in the way of precise work were increased by the condition of the atmosphere, which was often unfavorable on account of dust. Clearness was exceptional, and it was never safe to occupy a station far in advance, lest a sufficient number of control points in the rear should not be visible. In some instances it became necessary to remain on the mountain summits until toward sunset, to take advantage of the clearer atmosphere, which then sometimes follows upon an unfavorable condition during the day.

In the course of graphic triangulation, any errors of orientation which may creep in become speedily apparent in the triangle of error that is formed by the lines which should intersect in a point. The work from T'ang-hién to T'ai-yüan-fu checked out satisfactorily in this respect. As a final check a second base line was measured near T'ai-yüan-fu, at the close of the survey. Its position is shown on sheet B III. It is the distance between two conspicuous pagodas, which could not be measured directly as the line lay across the city, but which was determined independently by measuring, with care, a base line half a mile long, from which the distance between the pagodas was determined by triangulation with the theodolite.

The results of these two measurements were respectively, as follows:

	MILES.	KILOM'S.
Length of check base, as determined by graphic triangulation, extended from the initial base line at T'ang-hién and measured as nearly as possible on the field sheet on a scale of of 1: 90000	4.74	7.62
Length of check base, as determined by triangulation with theodolite from special short base measured for the purpose	4.68	7.53
Difference.	.06	.09

This result justifies confidence in the positions determined by triangulation. We consider them as reliable as the astronomical observations, with which they compare closely. The following table gives the positions for which we have determinations by both methods:

TABLE OF LATITUDES. SHOWING RESULTS BY GRAPHIC TRIANGULATION AND BY OBSERVATIONS ON POLARIS.

Place.	Position by graphic triangulation North latitude.	Position by observation on Polaris North latitude.	*Average.*
Wu-t'ai-shan.	39° 00′ 06″	39° 00′ 15″ 39° 00′ 22″	39° 00′ 18″
Wu-t'ai-hién.	38° 43′ 01″	. . . .	38° 43′ 17″
Han-yang	38° 19′ 49″	38° 20′ 41″ 38° 20′ 59″ 38° 20′ 32″	38° 20′ 44″
T'ai-yüan-fu	37° 52′ 03″	37° 52′ 26″ 37° 52′ 29″ 37° 52′ 20″ 37° 52′ 40″	37° 52′ 25″

If the above positions be compared it will be found that at Wu-t'ai-shan the difference is 12″, at Wu-t'ai-hién it is 16″, and at Han-yang 55″. Unfortunately an exact comparison cannot be made for T'ai-yüan-fu, as the astronomical observations were made in the inn in the heart of the city, and it was found impossible to locate it exactly with reference to the triangulation. As nearly as we can tell, however, the difference there is between 20″ and 30″. In all cases the position as determined by graphic triangulation is south of that by latitude observations, and the difference between the two seems to increase, at least to Han-yang. There is some reason to think that any error in triangulation was augmented between Wu-t'ai-hién and Han-yang, as the atmospheric conditions were very unfavorable on account of high winds and dust storms in that loess-covered district, and the wide expanse of the Hin-chóu basin was a serious obstacle to progress. But on their part the latitude observations lack refinement, since the verniers of the theodolite were graduated only to the nearest 15″, and they are also liable to a station error on account of deflection of the plumb-line among the high mountains. On the whole we consider the results of the graphic triangulation to be consistent and reliable.

The projections upon the sheets are controlled by azimuths, seven in all, observed by theodolite on Polaris at points along the line, namely; at Pau-ting-fu, which controlled the eastern end of the stadia traverse; at T'ang-hién, for the western end and the first of the triangulation points; at Li-yüan-p'u, Liu-yüan, Wu-t'ai-shan, and Han-yang, for intermediate points; and at T'ai-yüan-fu, for the southern end of the route.

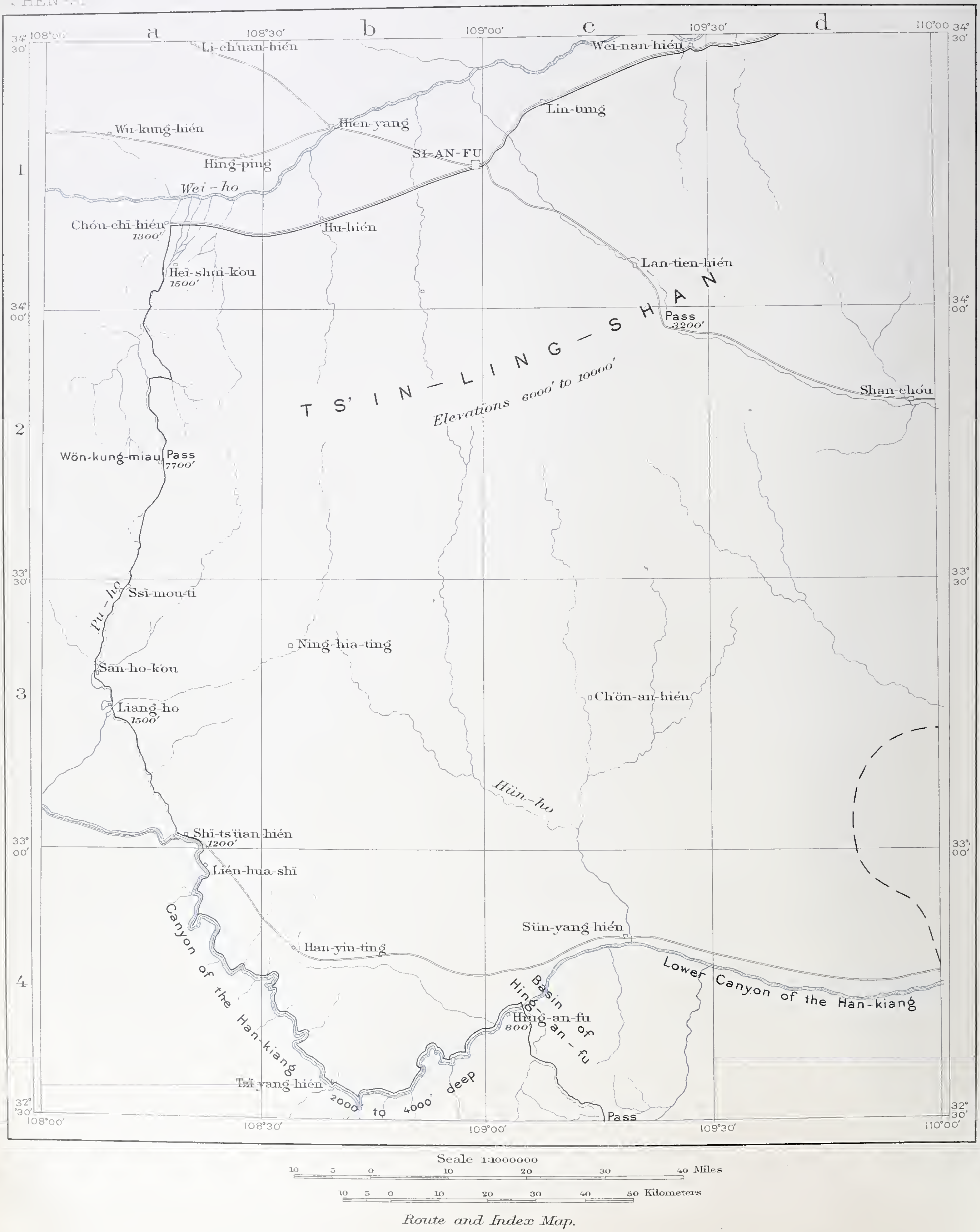
The determinations of elevation by triangulation and vertical angle checked out satisfactorily. The altitude of each station was determined a number of times by observations of vertical angle from as many other stations. The figures for the more important points are given in Table I, Appendix I.

From Pau-ting-fu to Wu-t'ai-shan we passed from an elevation of about 18 meters above sea to that of 3,050 meters, and thence descended to an altitude of about 825 meters at T'ai-yüan-fu. We believe these elevations to be within an error of 6 meters at Wu-t'ai-shan and of 15 meters at T'ai-yüan-fu, as compared with the railroad at Pau-ting-fu. The elevation of the railroad, which we necessarily took as the datum and which was given by the Belgian authorities at Peking as 18 meters, is not connected by a line of levels with mean tide, there being a break between the English road at Peking and the Belgian road at the same place, which has not been bridged by leveling.

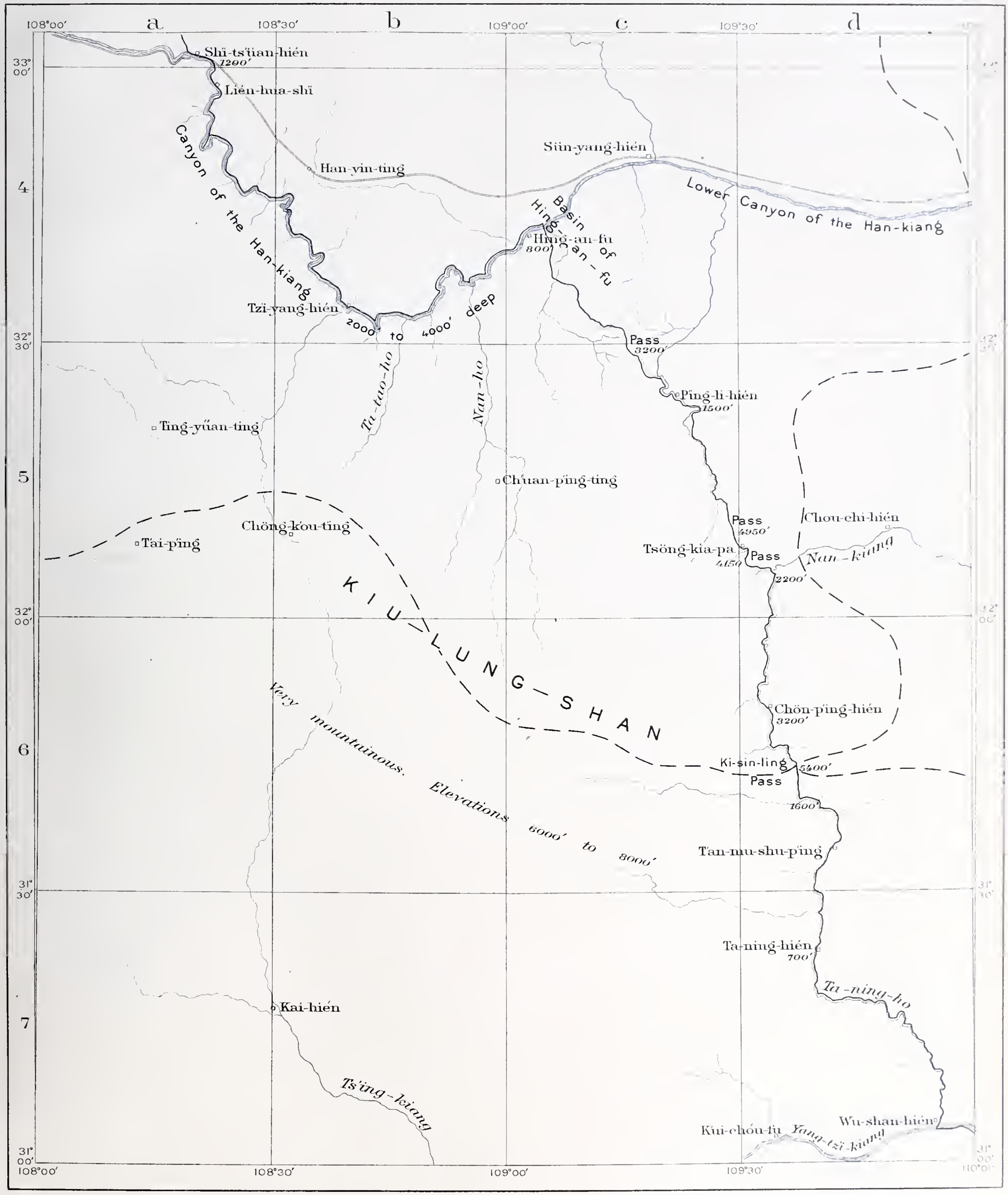
In addition to the graphic triangulation, which was executed between T'ang-hién and T'ai-yüan-fu, a continuous traverse of the road which we followed was run from T'ang-hién to Shï-tsui, a distance of about 145 kilometers. An attempt was made to do this by means of a specially built wheelbarrow and odometer, but in the mountainous country this was found impracticable, and the stadia method was substituted. From Shï-tsui to T'ai-yüan-fu the trail and road were sketched as accurately as possible between numerous points along the route which were located by triangulation.

Statistics of the Survey.

From T'ang-hién to T'ai-yüan-fu the graphic triangulation and accompanying route surveys were executed between the dates of January 9 and March 8, 1904. Fifty and a half days were spent in actual field work. The scale of the field map was 1:90000. The detailed topographic work covered an area from 8 to 40 kilometers in width and about 362 kilometers in length, comprising 7,000 square kilometers. Eighty-nine stations were occupied by plane-table and 1,783 points were intersected, an average of one point to every 4 square kilometers. The elevations of about 1,500 points were ascertained. Azimuths were observed at seven places, including Pau-ting-fu, T'ang-hién, and T'ai-yüan-fu.



Route and Index Map.



Scale 1:1000000

10 5 0 10 20 30 40 Miles

10 5 0 10 20 30 40 50 Kilometers

Route and Index Map.

SURVEYS IN SHEN-SI AND SSÏ-CH'UAN.

CHÓU-CHI-HIÉN TO TS'IN-LING SUMMIT.

Graphic Triangulation.—After traveling rapidly from T'ai-yüan-fu in Shan-si, along the well known highway to Si-an-fu, Shen-si, without executing any surveys, the topographic surveying was recommenced at the little city of Chóu-chï-hién in the Weï valley, about 65 kilometers west of Si-an-fu and 13 kilometers from the base of the great Ts'in-ling mountains. Our route lay across these mountains to the city of Shï-ts'üan-hién on the Han river, and we attempted to carry out an extensive topographic survey by graphic triangulation, as had been done in the northern mountains. Although high water and heavy rains interposed serious obstacles, we succeeded in this object as far as the summit of the Ts'in-ling range, but south of that divide the vegetation and forest cover, extending over even the highest summits, made it impossible to pursue the method without excessive loss of time in clearing the outlook around stations.

The survey from Chóu-chï-hién to the summit of the Ts'in-lings was begun by measuring a base line 1,773.7 meters long, in the creek bottom 3 kilometers south of the city. This base was measured twice and the two measurements differed .25 meters. Using the theodolite, the triangulation was expanded to the mountain summits near the front of the range, and their computed positions were platted on the plane-table sheet. The graphic triangulation was then expanded from the positions determined. The area thus surveyed is shown by the contours on atlas sheets *a* 1 and *a* 2.

The plane-table work required 8 days. There were 583 square kilometers of country mapped, 14 triangulation stations were occupied, 393 intersections were made, and about 375 elevations were ascertained.

TS'IN-LING SUMMIT TO SHÏ-TS'ÜAN-HIÉN.

Stadia Traverse.—At Wön-kung-miau, on the main divide of the Ts'in-ling range, we were able for the first time to see the country south of us, and the obviously unfavorable conditions led us immediately to abandon the graphic triangulation and begin the stadia traverse at that point. This traverse was confined to the route traveled, our rate of progress being too rapid to permit the topographer to occupy any side stations, except in the vicinity of San-ho-k'óu, where the complex relations of the valleys made a slight expansion of the work desirable. The traverse was run with the plane-table, which was oriented by a compass needle 10 centimeters long. Distances were measured by stadia and elevations by vertical

angles. Throughout the greater portion of the distance little could be seen away from the immediate line of survey, as the route lay in a deep and often wooded valley. The traverse was begun on May 2 and finished May 10, and occupied 7 days. It was 99 kilometers long and 252 stations were occupied.

The astronomical control of the survey from Chóu-chï-hién in the Weï valley to Shï-ts'üan-hién in the Han valley, was limited by bad weather to one observation for azimuth and two for latitude. The observations for latitude were made at Liu-yüé-ho, on the northern slope of the Ts'in-ling range, and at Shï-ts'üan-hién, the southern end of the traverse. The length of the survey was adjusted to the distance between these two points, as thus determined by the observed latitudes, there being no other control; and it was of course intended that the parallels of latitude should be placed in accordance with these observations; but in executing the draughting an error of about 20″ was made and not discovered until all the maps were engraved. It was then too late to change them, and in consequence all points between Chóu-chï-hién and Shï-ts'üan-hién are platted 20″ south of their proper positions. This error also enters into the adjustment of the boat traverse of the Han-kiang, but does not extend to Hing-an-fu and points south of that city, as they were correctly located in accordance with independent observations.

For longitude, that of Chóu-chï-hién was accepted as measured from the German Plankammer map, on a scale of 1:1000000, and was taken as 108° 18′.

With reference to elevation above sea for this survey across the Ts'in-ling mountains, we were without an accurate datum. Three aneroid barometers had been carried from T'ai-yüan-fu and simultaneously read twice a day during the journey to Chóu-chï-hién. These readings were carefully compared and checked by consideration of later readings and of the state of barometer at the Jesuit observatory at Shanghai on the same dates; and the altitude of Chóu-chï-hién, determined from them to be 403 meters above sea, was accepted as the best available datum. According to this elevation the summit of the Ts'in-ling mountains at Wön-kung-miau is 2,340, and that of the city of Shï-ts'üan-hién 366 meters above sea. In crossing the range we saw to the southwest a group of mountains already described by David and von Richthofen, the Ta-pai-shan or Great White Mountains. Their position was determined by intersections on the principal summits to be 40 kilometers southwest of Wön-kung-miau, and their altitudes between 3,500 and 3,750 meters.

Near Pa-kua-miau, southern Shen-si, atlas sheet c 5. Scene on principal highway of the district, illustrating soil-covered and partly wooded slopes and terraced spurs of uplands between P'ing-li river and the Nan-kiang.

Near Chön-p'ing-hién, southern Shen-si, atlas sheet d 6. View in canyon in Cambro-Ordovician limestone, looking upstream toward a more open valley developed in overlying shales; showing manner in which the river cuts across the structure of the region.

SHÏ-TS'ÜAN-HIÉN TO HING-AN-FU.

Boat Traverse of the Han River.—From Shï-ts'üan-hién we proceeded to Hing-an-fu via the Han river, by means of a houseboat. The distance of 169 kilometers was traversed in about two and one-half days, from May 12 to May 14, the boat being laid up over night. We floated with the current, which varied greatly, there being long reaches interspersed with shorter rapids.

The conditions did not permit us to stop frequently, as would have been necessary for any method of accurate measurement of distance, and we were therefore obliged to restrict the topographic work to a simple traverse, the courses being noted by compass and the distance being determined by time observations and estimates of the rate at which we were moving during each interval. When platted, the survey was adjusted to the latitude observations obtained at its two ends, Shï-ts'üan-hién and Hing-an-fu, and was found to be one-fourth of a minute out, north and south. The east and west distance was made to conform to the longitudes of the two ends, and this section of reconnaissance was thus inserted between the two more accurately surveyed sections, which it connects. As we had no means of noting the special topographic features of the magnificent canyon of the Han river, we have not attempted to contour the mountains, but have indicated the steep slopes by the conventional symbol of hachures.

HING-AN-FU TO WU-SHAN-HIÉN.

Stadia Traverse.—From Hing-an-fu to the Yang-tzï river our route lay through a very mountainous country with luxuriant vegetation. The greater part of the way was made on foot, as indeed was commonly the case elsewhere. On reaching the Ta-ning-ho, a tributary of the Yang-tzï, we again took boats and ran the swift stream to Wu-shan. A stadia traverse was carried by plane-table, with orientation by compass and elevations by vertical angles, precisely as had been done between Wön-kung-miau and Shï-ts'üan-hién. The direction was nearly north and south, and the distance was checked by latitude observations at Shuang-ho-k'óu, Ts'öng-kia-pa, Ta-miau-ssï, Ta-ning-hién, and one point on the Ta-ning-ho about 16 kilometers from the Yang-tzï. To these observations the maps are adjusted. For longitude, that of Wu-shan-hién, as given on the German Plankammer map on the scale of 1:1000000, was accepted (109° 55′). It was afterwards found that Le Chevalier had determined it as 109° 50′.

For altitude above sea the elevation of Wu-shan-hién, 64 meters as determined by our aneroid barometers in comparison with Shanghai, was adopted and applied to all the elevations for which the differences had been determined in the course of the survey from Hing-an-fu.

The traverse from Hing-an-fu to Wu-shan-hién was 278 kilometers long, 209 kilometers being made on foot and 69 by boat. 627 stations were occupied, 412 points intersected, and 756 square kilometers mapped. The work, which was begun on May 16, was completed on June 6, 20½ days having been spent in actual field work.

MAGNETIC DECLINATIONS.

Observations for magnetic declination were made from time to time in connection with the observations for azimuth. The method employed was that in use by the topographic parties of the United States Geological Survey. The true azimuth having been ascertained, and a line corresponding to it drawn upon the plane-table, a special box compass is set in the magnetic meridian and a line is drawn along its edge to intersect the true meridian. The angle between the two lines then represents the magnetic declination. The following is a tabular statement of the positions and amounts of the magnetic declination.

The results have been considered by Professor L. A. Bauer, chief of the magnetic work of the Carnegie Institution of Washington, and we are indebted to him for suggestions in regard to determining the index error of the compass.

VALUES OF MAGNETIC DECLINATION IN CHINA.

Date 1904.	Latitude north.	Longitude east of Greenwich.	Approximate local time.	Magnetic declination (west)	Atlas sheet.
	° ′	° ′	h	° ′	
June 5	31 09	109 55	6 p. m.	0 59	c1
" 3	31 22	109 40	10 a. m.	0 59	d7
May 17	32 39	109 05	10 a. m.	0 59	c4
" 10	33 02	108 19	10 a. m.	1 00	a3
Mar. 7	38 00	112 26	4½ p. m.	1 58	A III
" 6	38 04	112 37	5 p. m.	1 45	B III
Feb. 29	38 15	112 50	4 p. m.	1 25	B II
Mar. 8	38 20	112 48	11 a. m.	1 58	B II
Feb. 14	38 38	113 21	4½ p. m.	2 46	C I
" 19	38 42	113 11	4 p. m.	2 26	C I
" 13	38 43	113 20	12 (noon)	2 22	C I
" 11	38 46	113 24	12 (noon)	2 22	C I
Jan. 29	38 50	113 40	5 p. m.	2 8	D II
Feb. 5	38 58	113 30	4½ p. m.	4 9*	C I

* At this station, upon trial, it was found that the rock formation was sufficiently magnetic to give rise to local disturbance.

The Kiu-lung range, southern Shen-si, south of Chön-p'ing-hién, showing approach to Ki-sin-ling pass at an altitude of 5,400 feet.

On the Ta-ning-ho, southern Shen-si, 6 miles below Ta-ning-hién, atlas sheet d 7. View taken at point where the river emerges from a gorge cut across an anticline in Carboniferous limestone, illustrating the profound canyons which characterize the middle Yang-tzï and its tributaries.

The above results were obtained only incidentally in the course of the topographic work and can not make pretense to a greater accuracy than about $\pm\frac{1}{4}°$. The index error of the compass was determined by occupying the U. S. Coast and Geodetic Survey magnetic station at Tombstone, Arizona, in December, 1904. To the results as given above the index correction has already been applied.

SUMMARY.

The following is a summarized statement of the topographical work accomplished:

Graphic triangulation by plane-table, with delineation of contours; scale 1:90000.

Days of plane-table work		58.5
Area mapped	Square kilometers 7,500....square miles	2,900.
Triangulation stations occupied by plane-table		103.
Points intersected		2,181.
Elevations of points other than stations		2,000.
Average area per day	Square kilometers 128.20...square miles	49.58
Average plane-table stations occupied per day		1.76
Located points per	Square kilometer .30......square mile	.78
Elevations per	Square kilometer .28.......square mile	.72

Stadia traverse, with plane-table and altitudes by vertical angles; scale 1:90000.

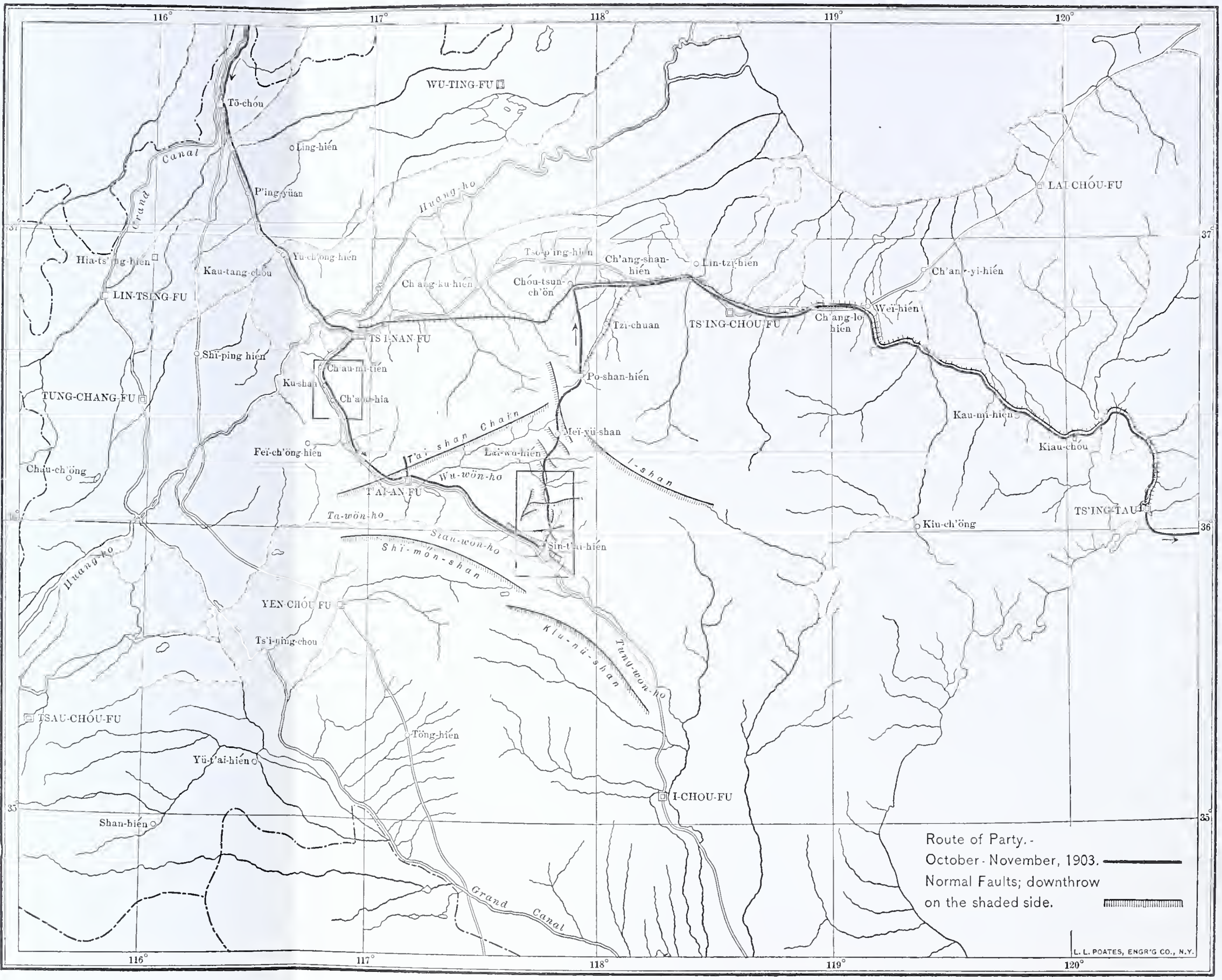
Days of traverse		31.5
Distance traversed	Kilometers 418............miles	260.
Area sketched	Square kilometers 1,040....square miles	400.
Stations occupied by table and rod		1,052.
Intersected points		400.
Elevations of points other than stations		375.
Average area per day	Square kilometers 33.33....square miles	12.7
Average distance traversed per day	Kilometers 13.27..........miles	8.25
Located points per	Square kilometer 1.38....square mile	3.63
Elevations per	Square kilometer 1.36.....square mile	3.57

Astronomical control:

Latitudes observed	14.
Azimuths observed	11.

Traverse by boat from Shï-ts'üan-hién to Hing-an-fu	Kilometers 169..........miles	104.5

Tables of altitudes and notes of the traverse of the Han river will be found in the Appendix



Scale 1 : 2,000,000

10 0 10 20 30 40 50 60 Miles

10 0 10 20 30 40 50 60 70 80 90 100 Kilometers

NORTHEASTERN CHINA.

SECTION I

NORTHEASTERN CHINA

PROVINCES OF
SHAN-TUNG AND LIAU-TUNG

				Feet.	Meters.	Present land surface.
Tertiary.		Wön-ho conglomerate.	Tw	0–150	0–45	Coarse conglomerate of limestone pebbles and blocks.
		Unconformity.				
Permo-Mesozoic.		Sin-t'ai formation.	PMs	indet.		Massive red clays with seams of coarse conglomerate and sometimes of limestone.
				200±	60±	Sandy gray shale and thin strata of sandstone.
				300±	90±	Red earthy sandstone strongly cross-bedded. (Contact not observed.)
		Unconformity?				
Upper Carboniferous.	Shan-si.	Po-shan formation.	Cp	700+	245	Shales and sandstone of yellow, brown, gray, and black colors, with local basalt flows. Coal seams and black limestone in dark shales.
		Unconformity.				
Ordovician.	Sinian.	Tsi-nan limestone.	€Ot	2,500	760	Dark dolomitic limestone in massive strata. Occasional thin layers of argillaceous gray limestone and calcareous shale.
				300	90	Gray impure limestone with local shale and crystalline dolomite.
Cambrian.	Kiu-lung group.	Ch'au-mi-tién limestone.	€cm	400 to 600	120 to 185	Massive blue-gray limestone.
		Ku-shan shale.	€k	50-150	15 to 45	Green shales and thin limestones.
		Ch'ang-hia limestone.	€ch	400 to 500	120 to 150	Gray or dark limestone partly oolitic; more or less replaced by green shale.
		Man-t'o shale.	€m	500 to 580	150 to 175	Shales of brown, maroon, red, and yellow colors, with thin seams of gray and buff limestone.
		Unconformity.				
		T'ai-shan complex.	ARt			Gneisses and schists intruded by granite.
		Total		5,450 to 6,080	1650 to 1845	

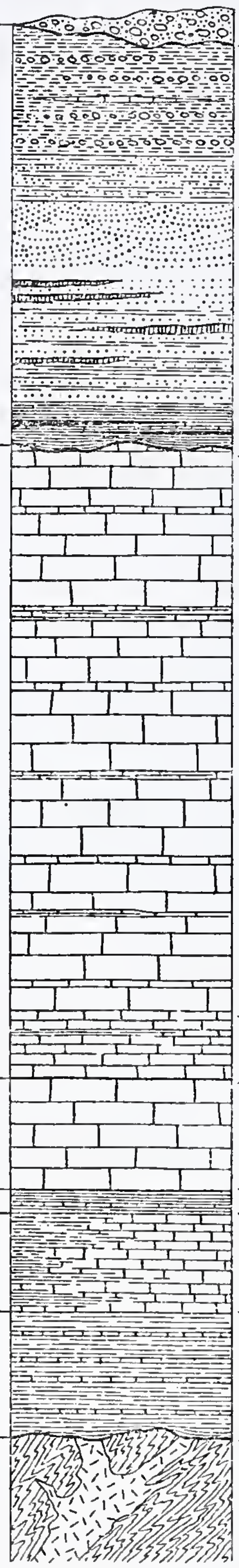


FIG. 1.—GENERALIZED SECTION OF SEDIMENTARY ROCKS OF WESTERN SHAN-TUNG.

CHAPTER II.

STRATIGRAPHY OF SHAN-TUNG.

By Eliot Blackwelder.

The formations which we saw and discriminated along our route of travel in Shan-tung range from the Pre-Cambrian to the present. The Pre-Cambrian is represented by a single great system, which we have called the T'ai-shan complex. Among the Paleozoics there are two; the Sinian system and the Shan-si coal-bearing system. Strata belonging to the Permian, Mesozoic, or Tertiary were not definitely identified, though Post-Carboniferous rocks are present in considerable thickness. The superficial deposits are chiefly Quaternary, but may include late Tertiary.

PRE-CAMBRIAN.

T'AI-SHAN COMPLEX.

The oldest rocks which we found in Shan-tung belong to a metamorphic complex, the constituents of which are largely igneous, though perhaps, in part, sedimentary in origin. The formation is broadly exposed in the central part of the province, and is typically developed in the T'ai-shan mountain range. The complex may be divided into three groups of rocks.

(1). Schists and gneisses, most ancient.

(2). Granites, relatively little altered.

(3). Dike-rocks, younger than the granites.

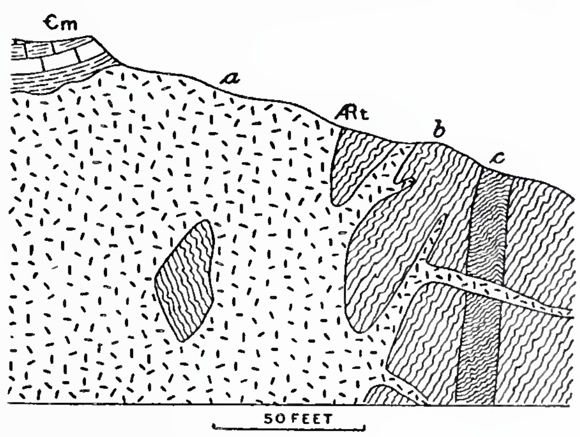


Fig. 2 (Blackwelder).—Ch'ang-hia, Shan-tung. Detail of T'ai-shan complex, showing ancient gneiss intruded by a schistose dike and the two cut by massive granite. On the left appears the unconformity at the base of the Cambrian. *a* = red granite; *b* = gray gneiss; *c* = black schistose dike.

Ancient Schists and Gneisses.

The prevailing rock in the first group is a banded gray gneiss of medium grain, composed of quartz, orthoclase, and biotite, with accessory minerals. There are numerous variations from this prevailing type. In the T'ai-shan range itself, the gneiss sometimes contains more hornblende than biotite,

and in other phases chlorite is the dominant dark mineral. There are also variations in texture, from fine-grained varieties in which the banding is minute, to coarser varieties containing prominent eye-spots of feldspar.

There are schists, most of which are dark greenish or blackish rocks composed of quartz and hornblende, with or without biotite. Some of the varieties are not well cleaved, and the fracture surfaces are brilliant with the shining hornblende crystals. Chloritic greenstones occur, but rarely.

The rocks of this first group are so thoroughly metamorphosed and so complexly folded that it is difficult to study their relations to each other. The schists have the composition of igneous rocks, but the available data do not suffice to preclude the idea that they may be in part of sedimentary origin. The gneiss is probably an ancient granite, which was intruded into the schists and subsequently metamorphosed. The relation was not satisfactorily determined in the field, but the schists were frequently found included in the gneiss in the form of irregular bodies, as if they had been imbedded in the granite at the time of intrusion.

Some of the biotitic schists occur as dike-like masses traversing both the gneiss and the older schists (see Fig. 2); evidently they represent basic intrusions later than the gneiss.

Granites.

In many exposures of the Pre-Cambrian nothing is found but a medium-grained red granite, composed largely of orthoclase, quartz, and biotite. In the T'ai-shan and also in other localities, there are pale gray granites which lack the red feldspars; and greenish varieties which owe their color to an unusual amount of epidote and chlorite. Hornblende is lacking in all of the T'ai-shan granites. Most of these rocks are fine-grained, and they seldom exhibit a distinctly gneissoid structure. Microscopic examination, however, shows that they have suffered more or less severe deformation.

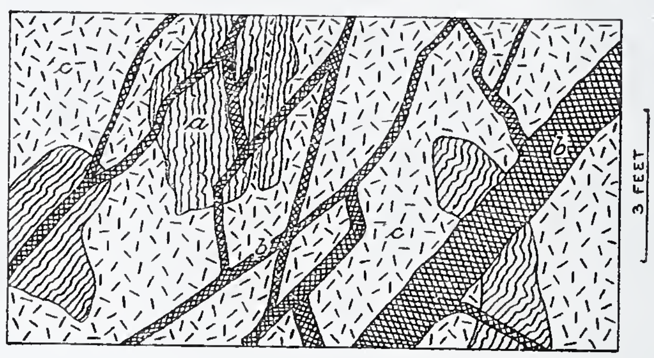


Fig. 3 (Blackwelder).—Ch'ang-hia, Shan-tung. Massive red granite including fragments of ancient gneiss crossed by veins of pegmatite. a = banded gray gneiss; b = pegmatite vein; c = red granite.

The granites occur either in large batholitic masses, or in dikes which emanate from these central bodies. The dikes cut across the schists and gneisses in such a way as to show clearly that the granites are intrusives of later age, probably Algonkian. Near the borders of the granitic

intrusions the older rocks are usually intersected by numerous veins of quartz and red or white pegmatite, which were in some cases traced into actual connection with dikes of granite. Some of the quartz veins, however, fill fissures and fault-planes in the granite itself, and must therefore be considered younger than the pegmatites and veins just mentioned (Fig. 3).

Later Intrusives.

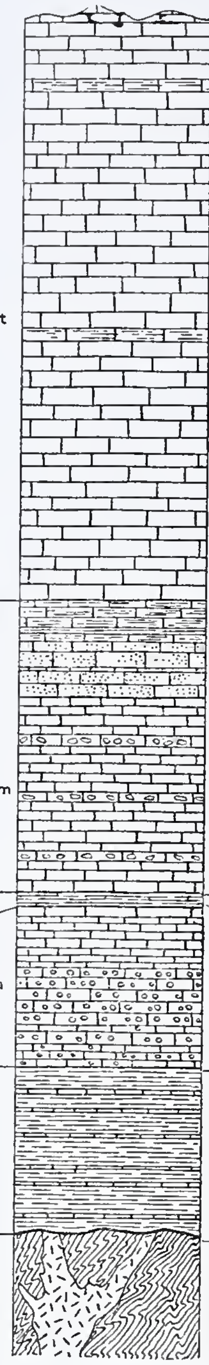
There are associated with the T'ai-shan complex certain igneous rocks, which are but little deformed and are younger than any of the members previously mentioned. Some of them are certainly Pre-Cambrian in age, while others are Post-Carboniferous; in the majority of cases, however, it is not possible to determine whether a given dike belongs to the T'ai-shan complex or is to be referred to a later system. In the east base of Man-t'o butte, in the Ch'ang-hia district, a greenstone dike, which traverses the red granite, is cut off at the unconformity beneath the Cambrian shales. The altered basalt dikes on the T'ai-shan are believed to be Post-Cambrian because they resemble certain dikes in Sinian strata farther to the east.*

UNCONFORMITY AT THE BASE OF THE SINIAN.

In the districts which we visited in Shan-tung, there is always a marked unconformity at the base of the Sinian system. The hills on the west side of the valley at Ch'ang-hia afford excellent opportunities to study this contact. Other exposures, equally as good, are to be found between Sin-t'ai and Yen-chuang, and elsewhere wherever the Sinian system and the basal complex are found in undisturbed relations. The basal sediments lie upon a relatively flat surface, which has been sculptured from the T'ai-shan complex—a plain so well developed that the hard granites and soft schists had been reduced approximately to common base-level. The absence of coarse, clastic sediments at the base of the Cambrian indicates that, as the sea finally invaded this ancient peneplain, it encountered few, if any, prominent inequalities and that opportunities for coastal erosion were at a minimum.

The time represented by this unconformity is a period long enough to admit at least the uplift of the region and a subsequent epoch of erosion sufficient to uncover the granites and to reduce both hard and soft rocks to a plain. The break may also represent a much greater lapse of time, corresponding to epochs of erosion and deposition, of which the record

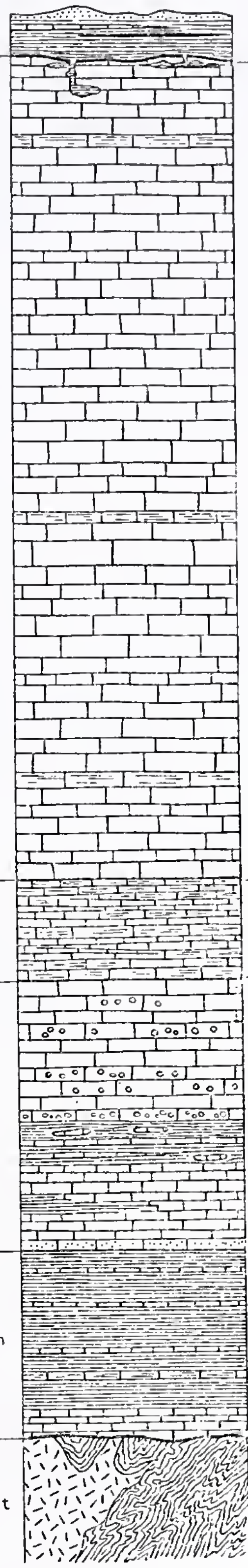
* Detailed and systematic descriptions of the different varieties of metamorphic and igneous rocks found in the T'ai-shan complex are given in the special report on Petrography, Chapter XVI.



				Feet.	Meters.	Present land surface.
Sinian.	Ordovician.	Tsi-nan dolomite.	€Ot	1800	550	Dolomitic limestone, dark gray and liver-brown colors.
				300	90	Shaly gray limestones and shales, buff crystalline dolomite, and thin white limestone.
	Cambrian.	Ch'au-mi-tién limestone.	€cm	600	180	Blue-gray limestone, conglomeratic at various horizons.
		Ku-shan shale.	€k	50	15	Green shale and slabby limestone.
		Ch'ang-hia limestone.	€ch	500	150	Gray limestone mottled with ocher. Dark gray oolitic limestone. Olive gray oolitic limestone.
		Man-t'o shales.	€m	500	150	Brown shale with thin gray limestones. Buff and gray shales with gray and buff earthy limestone and black slabby limestone.
T'ai-shan.	Archean.	T'ai-shan complex.	ARt			Schists and gneisses with intruded granite, syenite, etc.

Total................. 3,750 1,135

FIG. 4.—SECTION OF THE SINIAN SYSTEM IN THE CH'ANG-HIA DISTRICT, SHAN-TUNG



				Feet.	Meters.	
Sinian.	Carb	Po-shan series. —Unconformity—	Cp	150	45	Coal-bearing shales, etc.
	Ordovician.	Tsi-nan dolomite.	ЄOt	2,500	760	Dolomitic limestone, liver-brown, blue-gray, and purplish colors.
				300	90	Ash-gray earthy limestone, partly shaly
	Cambrian.	Kiu-lung group.	Єkl	800	245	Blue-gray limestone. Green shales, limestones, and limestone nodules. Oolitic dark limestone.
		Man-t'o shales. —Unconformity—	Єm	575	175	Brown shales and limestones. Maroon and yellow shales. Buff shales and earthy limestones.
T'ai-shan.	Archean.	T'ai-shan complex.	ARt			Gneiss, schists, and granite.

Total................ 4,375 1,315

FIG. 5.—SECTION OF THE SINIAN SYSTEM IN THE SIN-T'AI DISTRICT SHAN-TUNG.

has been destroyed. Masses of Pre-Cambrian quartzite, marble, and schists occur elsewhere in Shan-tung, infolded with the gneiss.* It is therefore highly probable that Algonkian sediments were spread generally over the province, that they were subsequently folded with the basal complex, and very largely removed by erosion. In that case the Pre-Sinian unconformity includes the time of their deposition, deformation, and erosion. It is certainly one of the first magnitude.

SINIAN SYSTEM.

The Sinian system of von Richthofen, a succession of sedimentary strata of Cambrian and Ordovician ages, is exposed over wide areas in central Shan-tung. The rocks are mostly limestones and shales, which vary in sequence considerably from place to place. For general discussion, therefore, it is expedient to discriminate only three groups of strata, of such a nature that they can be recognized throughout the province in almost all localities where the Sinian rocks occur. These are (1) the Man-t'o formation, a shaly series partly of Lower Cambrian age; (2) the Kiu-lung group, a variable series of limestones and shales of gray and green colors, containing Middle and Upper Cambrian fossils; and (3) the Tsi-nan formation, a massive limestone, uniform and continuous, which represents a part of Ordovician time and perhaps a portion of the Upper Cambrian.

MAN-T'O FORMATION.

The Man-t'o formation is primarily a series of red and brown shales with interbedded gray and buff limestones, which are usually of an earthy composition. These strata were seen in the slopes below the cliffs on all sides of the village of Ch'ang-hia, in the hills northeast of Sin-t'ai-hién, in those between Kau-kia-p'u and Yen-chuang and again 19 to 24 kilometers south of Po-shan. The total thickness ranges from 135 to 225 meters.

In the Ch'ang-hia District.

Stratigraphy.—The isolated butte called Man-t'o-shan, just south of Ch'ang-hia, contains a complete and well-exposed section of the Man-t'o formation, from the unconformable contact with the granite below to the conformably overlying limestones. As this section is considered typical the formation is named from the butte. Similar strata are exposed on either side of the valley, in outcrops prevailingly of red and brown color, beneath limestone cliffs (Fig. 6).

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* See von Richthofen, China, vol. II, pp. 201, 213–219; and Lorenz, Beiträge zur Geologie und Paleontologie von Ost-Asien, p. 8.

The basal layers of the Man-t'o are usually soft, white, or yellowish clays of fine texture, which, even at the contact with the Pre-Cambrian, contain no appreciable amount of conglomerate or arkose. The lower portion of the Man-t'o, for about 60 meters above the base, consists of pale, earthy limestones and varicolored shales, alternating in layers 15 centimeters to 9 meters thick. Among the more continuous beds are two buff-gray argillaceous limestones, one about 3 meters thick overlying the basal clays, the other varying from 3 to 9 meters in thickness and situated 36 meters above the first. Each of these limestones produces a prominent ledge in the slopes where they are exposed. The associated shales are variable

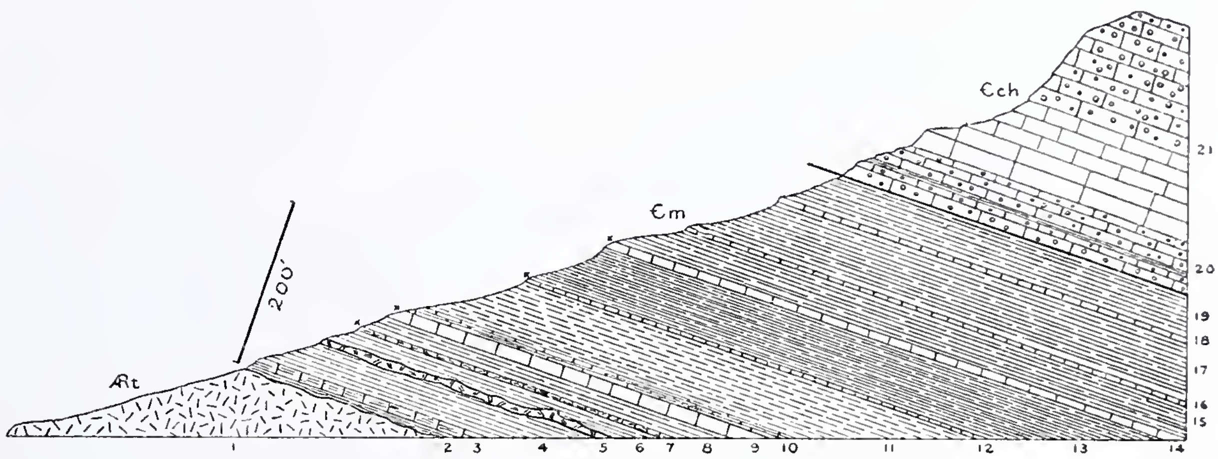

Fig. 6 (Blackwelder).—Ch'ang-hia, Shan-tung. Section of Cambrian strata in the north side of Man-t'o butte. 1 = red granite; 2 = soft yellow shales; 3 = buff earthy limestone; 4 = gray and buff calcareous shales; 5 = syenite-porphyry sheet; 6 = greenish shale; 7 = earthy limestone; 8 = maroon shale; 9 = buff earthy limestone; 10 = white calcareous shale; 11 = red shale; 12 = olive gray limestone; 13 = dark shales; 14 = gray limestone; 15 = maroon shale; 16 = gray limestone; 17 = brown and gray shales; 18 = gray limestone; 19 = brown shale; 20 = thin-bedded, dark oolite and greenish shale; 21 = gray limestone with black oolitic bodies. The scale of thickness is indicated in feet.

when traced horizontally. Most of the layers are gray or buffish, and they often approach slaty limestones in character. Very thin beds of soft green, yellow, and maroon shales are, however, almost always present.

The next 36 meters consist largely of reddish, maroon, and yellow shales which are decidedly variable. Within these are two thin layers of limestone, which are gray and crystalline on fresh surfaces, but become olive or russet on weathered exteriors. Most of the sections show also a shaly red sandstone, 5 or 6 meters thick, at the top of the 36 meters mentioned. The remainder of the Man-t'o is fairly constant in its characteristics. It consists largely of dark shales of brown, maroon, and purplish tints. They are often sandy and micaceous. Gray crystalline limestone occurs in layers 2 centimeters to 1.5 meters thick, and also in lenticular nodules embedded in the dark shales. Two of the limestone beds are fairly continuous,

appearing in all sections examined, but the majority are of local development only. Fossils occur very sparsely in the shales and are usually not well preserved; but in the limestone layers and nodules they are often abundant, and, although fragmentary, are clear and distinct. In some layers the sections of the fossils, which appear on the weathered surfaces in great profusion, give the rock a streaked and spotted appearance which is striking. The upper Man-t'o faunas are rich in trilobites and brachiopods, which are in a general way similar to those of the North American Middle Cambrian.

The transition from the Man-t'o shale to the overlying Kiu-lung limestone is usually marked by a few feet of interbedded shales and slabby limestones, upon which the massive strata of the cliffs rest conformably.

Fossils from Man-t'o shale.—No fossils whatever have yet been found in the lowest 30 meters or more of the Man-t'o formation. About 36 to 45 meters above the base there is a thin member of fossiliferous slaty black limestone, which is associated with buff and brown calcareous shales and is constant over the whole district. On the hard black slabs fragments of a large trilobite are almost always preserved. This is *Redlichia chinensis* Walcott, a form closely related to the genus Olenellus. One rarely finds anything but spines and pieces of the free cheeks, but here and there an imperfect cranidium may be discovered. The fossils are visible only on the weathered surfaces, and it is therefore useless to split the rock open. Excepting an undetermined species of Redlichia and certain indeterminate fragments, no other fossils have been recognized at this horizon.

In the overlying portion of the formation fossils appear occasionally, but it is rare to find them in considerable abundance. The lowest horizon yet discovered is about 15 meters above the Redlichia limestone; it is the lowest of that succession of thin gray crystalline limestones, which is so characteristic a feature of the upper part of the Man-t'o shales. The stratum is usually only about 6 meters thick, and yet it is constant over most of this district. The fauna collected from this limestone presents little variety, but the individual fossils are rather abundant:

Ptychoparia mantoensis Walcott
Ptychoparia ligea Walcott

A similar gray limestone, only a few feet thick, forms a ledge in the slopes of shale about 25 meters above the last horizon mentioned. This contains abundant, although fragmentary, remains of several trilobites and one brachiopod:

Billingsella richthofeni Walcott
Ptychoparia mantoensis Walcott
Ptychoparia aclis Walcott
Unidentified trilobite fragments

The upper part of the formation, consisting of two thick beds of dark sandy shales with thin, gray limestones, frequently contains small, disk-shaped nodules of limestone, stained a deep, maroon color by iron oxides;

these nodules contain numerous fossils, the most abundant being cranidia of Ptychoparia spp.:

Obolella asiatica Walcott
Ptychoparia aclis Walcott
Ptychoparia granulosa Walcott
Ptychoparia impar Walcott
Ptychoparia impar (var.) Walcott

The upper shales appear to be almost barren, but fossils may be expected in any of the thin limestone strata which occur at various horizons in the upper half of the formation.

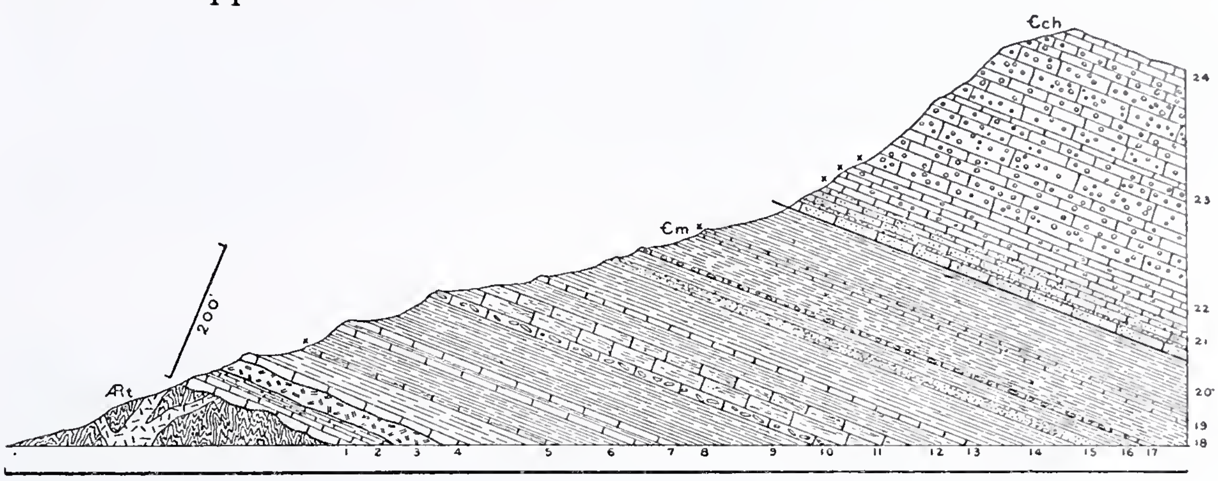

FIG. 7 (Blackwelder).—Sin-t'ai-hiên, Shan-tung. Section of Cambrian strata in the mountain northeast of the city. 1 = earthy limestone resting on gneiss; 2 = slabby gray limestone; 3 = porphyry sheet; 4 = dark hard limestone; 5 = gray calcareous shale; 6 = maroon shale; 7 = gray and buff earthy limestone and shale; 8 = gray shale; 9 = brown shale; 10 = greenish conglomeratic limestone; 11 = gray slabby limestone; 12 = brown shale; 13 = gray limestone; 14 = chocolate brown shale; 15 = shaly red sandstone; 16 = chocolate shale; 17 = gray conglomeratic limestone; 18 = brown micaceous shale; 19 = olive gray limestone and shale; 20 = brown shale; 21 = sandy brown and gray limestone; 22 = thin-bedded crystalline oolitic limestone; 23 and 24 = dense gray limestone. The scale of thickness is indicated in feet.

IN THE SIN-T'AI DISTRICT.

Stratigraphy.—The Man-t'o formation in this area is like that just described, so far as its general composition is concerned, but is somewhat thicker and more variable in its details (Fig. 7). The basal member is commonly an earthy buff limestone about 30 meters thick, which is separated from the granite below, in one instance, by a few inches of emerald green clay. In at least half of the sections the limestone contains intrusive sheets of greenish hornblende-syenite-porphyry. Above this basal limestone pale calcareous shales and argillaceous limestones range through a thickness of about 45 meters. Certain layers of the shales are brown or even reddish, and local strata in the limestones are dense gray or black rocks of superior hardness. On the surfaces of these slaty black limestones fragments of Redlichia again appear.

The upper portion of the Man-t'o comprises a rapid alternation of dark red and brown shales with thin gray limestones and occasionally a

little red sandstone. Various layers of the limestone are conglomeratic—a peculiarity which is more common in the Ku-shan and Ch'au-mi-tién members of the Kiu-lung group. In the Kiu-lung-shan, south of Yen-chuang, olive micaceous shales replace the usual brown shales at the top of the Man-t'o formation. Sections in this area show a sandy limestone at the base of the series which overlies the Man-t'o; the limits are thus rendered fairly definite.

Fossils from Man-t'o shale.—The Man-t'o formation in the Sin-t'ai district presents much the same characteristics as in the region farther north. The lower 35 meters or more have yielded no fossils whatever, but in limestones above this barren zone they occur at several horizons.

As before, the oldest fossiliferous layers are the slaty black limestones, upon the weathered surfaces of which fragments of Redlichia appear.

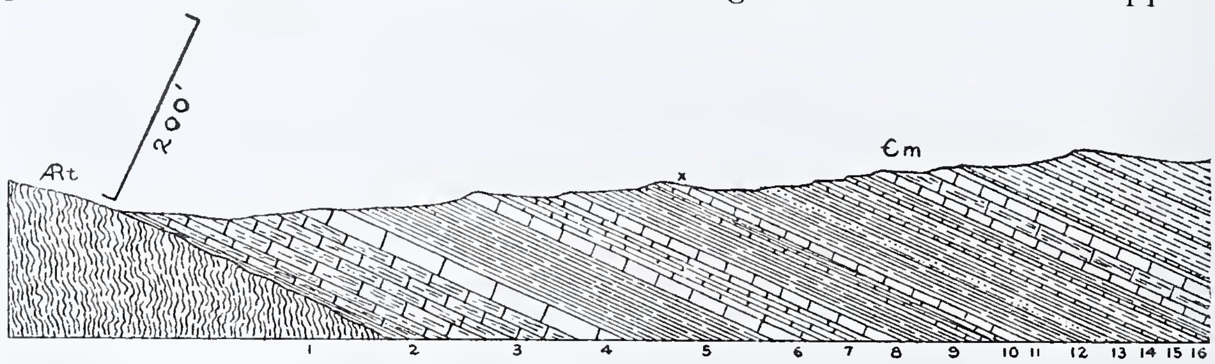

FIG. 8 (Blackwelder).—Yen-chuang, Shan-tung. Section of Cambrian strata in the western part of the Kiu-lung-shan. 1 = gray gneiss; 2 = bright green shale; 3 = gray earthy limestone; 4 = dense blue-black limestone; 5 = brown and yellow shale; 6 = blue-gray limestone; 7 = shaly gray limestone; 8 = dense blue-black limestone; 9 = yellow shale; 10 = gray limestone and shale; 11 = slaty black limestone; 12 = chocolate slate; 13 = brown shaly sandstone; 14 = yellow shale; 15 = buff earthy limestone; 16 = red shale. (Section continued in fig. 8*a*.)

The remains were, however, so fragmentary that a reference to the genus is all that seems possible at present.

An upper Redlichia fauna was discovered in the slopes of the faulted butte (Hu-lu-shan) south of Yen-chuang, and in the mountain (Huang-yang-shan) east of the butte. The fossils occur in a finely crystalline dark gray limestone, a little more than 30 meters above the black slates just mentioned, and although fragmentary, they were well preserved and are revealed by breaking the rock. The species collected from this stratum include:

Billingsella richthofeni Walcott	*Ptychoparia constricta* Walcott
Stenotheca rugosa chinensis Walcott	*Redlichia nobilis* Walcott
Hyolithes delia Walcott	

Although fossils undoubtedly occur in some of the thin gray limestones in the upper half of the shales, none have yet been collected; except that some undeterminable fragments of Ptychoparia were found in a brown shale which lies at the top of the Man-t'o section.

KIU-LUNG GROUP OR FORMATION.

The Kiu-lung division takes its name from the Kiu-lung (Nine Dragon) range of hills south of Yen-chuang in the Sin-t'ai district. The rocks of this widely distributed group occur along our route in the hills about the villages of Ch'au-mi-tién and Ch'ang-hia, in the low pagoda hill near T'ai-an-fu, in the hills 16 kilometers southeast of the same city, in the mountains in the Sin-t'ai-Yen-chuang district and about 16 kilometers south of Po-shan. The members of the group are subject to marked horizontal variations, a thick hard limestone sometimes grading off into shales within a few miles. Thus the subdivisions which may be distinguished in one locality are not readily recognizable in others. The total thickness varies from 275 to 335 meters.

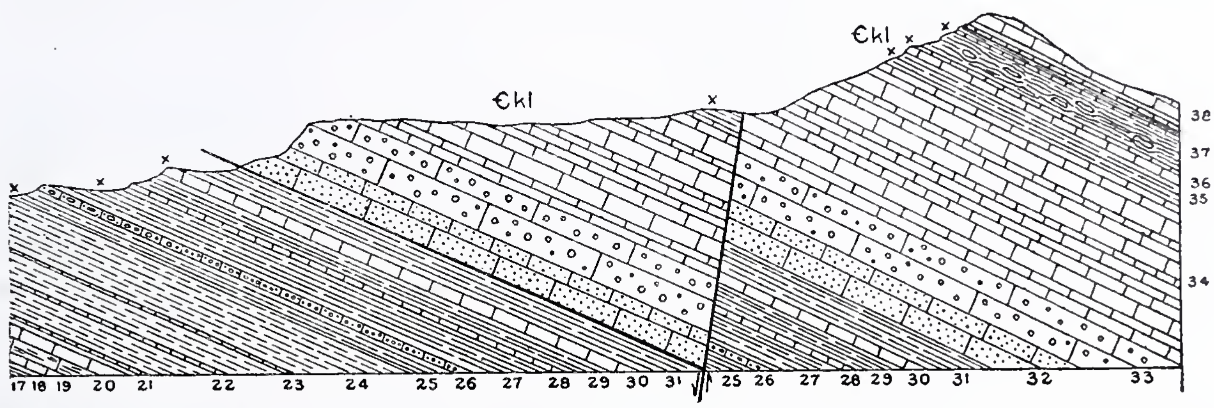

FIG. 8*a*.—17 = black limestone; 18 = yellow shale; 19 = purple-gray limestone; 20 = gray limestone; 21 = yellow shale and thin limestone; 22 = red shale and thin limestone; 23 = green-gray limestone; 24 = red and yellow shale; 25 = maroon shale; 26 = greenish conglomeratic limestone; 27 = brown shale; 28 = buff earthy limestone; 29 = olive green shale; 30 = cross-bedded green-gray limestone; 31 = olive shale; 32 = gray sandy limestone; 33 = hard dark oolite; 34 = light and dark gray limestone; 35 = green shale; 36 = dense gray limestone; 37 = green nodular shale and thin limestone; 38 = massive dark limestone. The scale of these figures is indicated in feet.

IN THE CH'ANG-HIA DISTRICT.

CH'ANG-HIA LIMESTONE.

Stratigraphy.—In the region about Ch'ang-hia and Ch'au-mi-tién three distinct formations are recognized in the Kiu-lung group. The first to be described is the lowest, the Ch'ang-hia oolite. Overlying the soft strata of the Man-t'o rest about 150 meters of massive limestones, which form cliffs several hundred feet high. From the prominence of these cliffs in the neighborhood of Ch'ang-hia, the formation has been named the Ch'ang-hia limestone or oolite. The lowest strata consist of about 18 meters of thin-bedded olive-gray limestones, which are in part oolitic. Then follow the massive, cliff-making beds of black oolite, having an average thickness of 75 meters. This limestone is dull gray in ground color and sometimes has a tinge of green, derived from grains of glauconite; but it is rendered much darker by the abundant oolitic nodules, which are blackish. In the gentler slopes above the cliffs there are about 30 meters of crystalline

limestone, which is often locally oolitic, and is for the most part dark gray in color with tinges of purple.

The upper portion of the Ch'ang-hia formation is composed of a somewhat variable succession of dark and light gray limestones which are occasionally oolitic, more frequently coarsely crystalline, but prevailingly dense and ringing. Many of these layers are indefinitely mottled with ocherous coloring matter, which is distributed in cloudy masses, regardless of rock structure. Harder layers in this group often produce a second cliff, but this is never so marked a feature as that made by the black oolite.

Near the top of the formation the conglomeratic limestones appear. As a rule they are light gray, but are interbedded with thin layers of pale green earthy material, which also often incloses the pebbles. Many of the layers are strikingly like ordinary conglomerates when the exteriors have been exposed to weathering.

Oolitic limestones.—The dark oolitic limestones, which are so characteristic of the Sinian system throughout China, deserve special mention in this connection. Von Richthofen noted and described these rocks,* and applied to them the name "globulitic limestone," being of the opinion that they were not true oolites. They should be distinguished from the conglomeratic phases of the Sinian limestones, which are quite different in aspect and are believed to be equally distinct in origin.

In its commonest phase the dark oolite has a gray matrix of minute calcite crystals. The oolitic bodies are dark brown or black, ranging in diameter from a fraction of a millimeter up to three or four millimeters. They are usually spheroidal in shape, but may be oval or ellipsoidal. When examined under the microscope these spherules are distinguished from the matrix by a slightly darker coloration and a dark periphery; there is frequently a suggestion of concentric rings within. The material of the spherule is granular calcite like that of the matrix. Very few of the spherules in this variety of the oolite possess distinct nuclei, and where such features are present they are usually indefinite masses of somewhat coarser grained calcite.

Another phase of the Cambrian oolites, represented by a specimen from the upper portion of the Man-t'o formation, shows the concentric structure conspicuously. In this rock the matrix is light-colored calcite, while the oolites themselves are deep red. These red spherules usually contain nuclei which, in some cases, can be identified as bits of marine shells. Around these nuclei there are concentric rings of very finely divided calcite, more or less colored by a red earthy material. About

* China, vol. II, pp. 196, 223.

the exterior of each spherule there is a fringe composed of needle-like crystals of calcite, all arranged with their axes perpendicular to the periphery.

There is still a third phase of the oolite, which is quite different from either of those described, and is represented by a specimen from the thin-bedded limestones at the base of the Ch'ang-hia formation. In this case the spheroidal bodies are coarsely crystalline, as may be seen in a glance at the hand specimen. Frequently individual spheroids consist of one crystal only, or there may be several rather large interlocking crystals in a group.*

The red oolite, the second one mentioned, has the usual character of oolites described from other countries. The first and third varieties, particularly the latter, are not so familiar. I am of the opinion, however, that they all belong to one category, namely, that they are true oolites in different stages of alteration. The several varieties of rocks of this character which we collected in China appear to form a graded series. The red variety just described is a typical unaltered oolite, in which the spherules are composed of distinct nuclei, surrounded by concentric layers of very finely divided calcite. The second step in the series is represented by rocks from the Sinian of the Yang-tzï gorges; in these there is a central nucleus which is distinctly crystalline, surrounded by faintly concentric layers, in which crystals are visible, though minute. The dark variety, first described as characteristic of the Ch'ang-hia limestone, represents a third stage; both nuclei and concentric banding are almost obsolete, and the entire spherule is composed of distinct interlocking crystals. Another specimen from the Yang-tzï valley shows even coarser crystals in the oolitic bodies. The last of this series is the third variety described above; here the calcite is so coarsely crystalline that individual spherules are not infrequently composed of a single crystal. In this last variety only a very few of the bodies show any traces of banding. On the basis of this series I advance the hypothesis that all of these rocks are oolites in different stages of crystallization; that the latter members of the series have been derived, by the crystallization of the minerals, from rocks similar, except in coloration, to the first variety. As the minute crystals of the true oolites are enlarged, the identity of the nucleus and of the concentric layers is gradually lost—the process apparently beginning at the center of the nodule and extending outward until the periphery is reached. When the entire mass has become distinctly crystalline we have a rock like the third specimen in the series. The logical continuation of the process results in the production of the coarsely crystalline fourth and fifth varieties. The possibility of this transformation depends upon the well-known fact

* For detailed descriptions of oolites from China see special report on Petrography, Chapter XVI of this volume.

that deposits of finely divided calcium-carbonate are slowly changed by the processes of metamorphism into crystalline limestone and marble.*

Fossils from Ch'ang-hia limestone.—The Ch'ang-hia limestone yields fossils at several horizons. Much of the series is barren, but fossils may be expected in greater or less abundance, in almost any of the strata from bottom to top. As a rule the more oolitic layers do not furnish many fossils, while, on the other hand, some of the non-oolitic strata contain an abundance of them. The fossils are always fragmentary; not once, in all our collecting in this district, were we so fortunate as to find a single complete trilobite. Since the fossils are dark bodies in a gray matrix, they are easily seen on freshly broken surfaces.

In the vicinity of the village of Ch'ang-hia, the massive cliff-making limestone, which is the most prominent member of the formation, is separated from the underlying Man-t'o shale by 24 to 30 meters of thin-bedded gray limestone, which is more or less oolitic in certain layers. Fossils are rather common in this limestone at several different horizons. We have one lot from the basal layers which includes:

Orthis (*Plectorthis*) *agreste* Walcott
Ptychoparia (*Liostracus*) *toxeus* Walcott
Ptychoparia titiana Walcott
Ptychoparia tenes Walcott

Another small collection from the middle of this thin-bedded member possesses no species in common with the last, although the two horizons are only 15 meters apart. The reason for this complete change of faunas in so slight a vertical range is not obvious; since the character of the rock indicates general uniformity in the conditions of deposition, we should expect a gradual change in the fossils contained, rather than an abrupt one. The list from this upper bed comprises:

Acrothele rarus Walcott (?)
Orthotheca daulis Walcott
Agraulos abrota Walcott
Anomocare latian Walcott
Anomocare eriopia Walcott
Ptychoparia theano Walcott

This thin-bedded gray limestone is followed by a massive, hard, cliff-making limestone, 60 meters thick. The rock is dark gray, often purplish or stained brown with iron oxides. It is the principal horizon for the peculiar black oolitic bodies mentioned above. On account of the difficulty of working with such massive strata, and also because the rocks are relatively barren, we found few fossils in this member.

Two small lots from the top of the cliffy limestone, as exposed east of the village of Ku-shan, have yielded:

Agraulos dryas Walcott
Dorypyge richthofeni Dames
Crepicephalus magnus Walcott

* For an account of these processes see U. S. G. S. Monograph XLVII, A Treatise on Metamorphism, Van Hise, pp. 796–797.

The upper portion of the limestone consists of an alternation of dark oolites, mottled ocherous limestones, and gray crystalline or aphanitic limestones, several layers of which are fossiliferous. In the basal layers of this upper series we found, at Ku-shan, abundant fragments of:

Arionellus alala Walcott
Arionellus sp. undt.
Menocephalus adrastia Walcott
Menocephalus agave Walcott
Menocephalus sp. undt.
Ptychoparia (*Liostracus*) *intermedia* Walcott
Solenopleura acidalia Walcott
Solenopleura agno Walcott
Shumardia sp. undt.

About 100 feet, 30 meters, higher, another meager fauna makes its appearance. The only identifiable remains are those of:

Stenotheca rugosa orientalis Walcott
Crepicephalus damia Walcott
Solenopleura sp. undt.

In the dark gray oolitic layers, about 400 feet, 120 meters, above the base of the Ch'ang-hia formation and nearly equivalent to the last horizon, some of these forms reappear in company with others not encountered in the lower strata. This lot includes:

Scenella clotho Walcott
Platyceras chronus Walcott
Stenotheca rugosa orientalis Walcott
Crepicephalus damia Walcott
Menocephalus acerius Walcott

Scarcely 20 feet, 6 meters, higher is a light gray, crystalline limestone, in which abundant, although fragmentary, remains of the following occur:

Stenotheca clurius Walcott
Arionellus alala Walcott

Another lot about the same horizon, in a section scarcely a mile away, adds to the list *Menocephalus acis* Walcott.

The uppermost layers of the Ch'ang-hia formation, through a thickness of 50 to 100 feet, 15 to 30 meters, are dense gray limestones, with many conglomeratic strata. Within this thickness several lots of fossils were secured, which, when combined, yielded the following list of species. The two trilobites *Anomocare? daulis* and *Dorypyge richthofeni* are among the most abundant and characteristic species at this horizon.

Acrotreta liani Walcott
Hyolithes cybele Walcott
Anomocare? daulis Walcott
Anomocare temenus Walcott
Anomocarella? bura Walcott
Damesella brevicaudata Walcott
Dolichometopus deois Walcott
Dolichometopus dirce Walcott
Dorypyge richthofeni Dames
Menocephalus belenus Walcott
Menocephalus admeta Walcott
Ptychoparia (*Liostracus*) *tutia* Walcott
Ptychoparia (*Liostracus*) *trogus* Walcott
Solenopleura abderus Walcott
Solenopleura acantha Walcott
Solenopleura agno Walcott
Arionellus alala Walcott
Crepicephalus damia Walcott
Crepicephalus, cf. *Crepicephalus magnus* Walcott
Agraulos divi Walcott
Agraulos agenor Walcott

KU-SHAN SHALE.

Stratigraphy.—The second formation of the Kiu-lung group is the Ku-shan shale, so named from a village near which it is well exposed. It lies conformably upon the limestones. This terrane is usually about 50 feet in thickness, but it is slightly variable in this respect as well as in its individual strata. Thin calcareous shales of light green color prevail. Minor layers of brown, purplish, and even yellow shales, with a few seams of dense limestone, make up the remainder of this member. So far as our observations go the shales are barren of fossils. Thin limestones in this shale member are usually conglomeratic, but they are rarely oolitic.

CH'AU-MI-TIÉN LIMESTONE.

Stratigraphy.—The third formation is the Ch'au-mi-tién limestone, which consists of the hard limestones that form the hills southeast and southwest of Ch'au-mi-tién. The rocks can be recognized in the field by the distinctly blue color of the exposures, while freshly fractured surfaces are usually very dark gray and finely crystalline. A transition belt between the Ku-shan shale and this limestone is characterized by 40 feet, 12 meters, of slabby limestones, which show preeminently the conglomeratic peculiarity. Two different phases of these conglomerates appear at this horizon. In one the pebbles are mostly less than 1 inch in length, are embedded in a dull olive-gray matrix, but are themselves dark red in color. This stain of iron peroxide does not penetrate deeply into the nodules, for in transverse sections it is seen that their centers are light colored. In this type of the conglomeratic limestones the pebble-like bodies are comparable to large beans, both as to size and shape. In the other phase mentioned, the red coloration is lacking and the pebbles average more than 2 centimeters in length, with a maximum of about 10 centimeters. They are flattish ellipsoidal or reniform. When the rock is viewed in horizontal section, as is frequently possible where it has been cut and polished in making monumental tablets, the concretions are seen to lie in no definite relation to each other, unless there be an obscure radiate arrangement. Their long axes point in almost every direction, some lying on edge, but the majority disposed with the flat sides parallel to the bedding. On weathered surfaces they stand out in relief, with external colors of dull russet or olive, and in their general aspect they resemble clastic conglomerates of the ordinary kind* (Plate LIII).

Upon this succession of thin-bedded limestones follow the gray beds of the Ch'au-mi-tién limestone in typical development. The limestones

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* For detailed discussion of these conglomerates, see special report on Petrography.

of this formation are never so thickly bedded as those of the Ch'ang-hia. Individual strata are usually not more than 5 or 6 feet thick, and at several horizons the rocks are decidedly slabby; many are dense and break with a conchoidal fracture. On weathered surfaces the rock is dark bluish gray. Flint is conspicuously absent from all of these Sinian limestones. The summit of the formation is marked by a change in the character of the sediments, the lower member of the next younger series being yellowish in color and notably dolomitic.

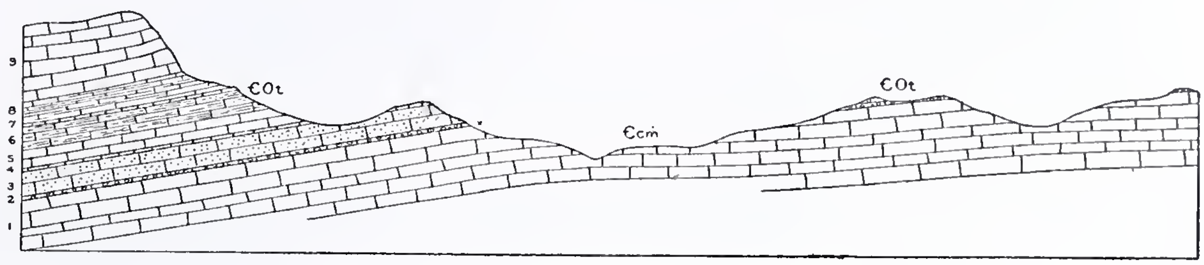


FIG. 9 (Blackwelder).—Ch'au-mi-tién, Shan-tung. Section of Upper Cambrian and Lower Ordovician strata in the ridge east of the village. 1 = dense blue-gray limestone; 2 = conglomeratic limestone; 3 = sandy yellow dolomite; 4 = white earthy limestone; 5 = buff crystalline dolomite; 6 = shaly gray limestone; 7 = blue-gray limestone; 8 = slabby yellow limestone; 9 = dense brown limestone.

The topographic expression of the Ch'au-mi-tién limestone differs from that of the other hard Cambrian limestone, the Ch'ang-hia oolite. Instead of forming abrupt and often vertical cliffs, it presents steep bluffs, in which the relatively thin-bedded strata make steps which can be ascended at almost any point.

Fossils from Ch'au-mi-tién limestone.—At a few restricted horizons, fossils, consisting chiefly of brachiopods and fragments of trilobites, are fairly abundant. Their affinities are with Upper Cambrian faunas of other countries. On account of the interruption, represented by the barren Ku-shan shales, it is not surprising that few, if any, of the Ch'ang-hia fossils pass up into this series. The important forms in this limestone are species of *Ptychaspis*, *Illænurus*, and the brachiopod subgenus *Plectorthis*. Almost all of the familiar genera which characterize the Ch'ang-hia limestone have completely disappeared.

In the base of the series, dense, slabby limestones, which are, for the most part, conglomeratic, predominate through the first 15 meters. From loose blocks, near the summit of the mountains at Ku-shan, we have specimens of *Chuangia batia;* it is probable they were derived from this basal portion of the Ch'au-mi-tién limestone.

About 100 to 120 feet, 30 to 36 meters, above the base of the formation, and near the top of a characteristic, purplish gray limestone of superior hardness, fossils were found in abundance. Strange to say, out of several

lots collected from approximately the same horizon, within a radius of not more than 2 miles, only three species occur in two of the lots and only one in three of them. This last is *Illænurus canens*, an abundant trilobite, which is present in most assemblages of fossils from the lower part of this limestone. The entire list from this horizon includes:

Agnostus chinensis Dames
Illænurus canens Walcott
Illænurus ceres Walcott
Pagodia macedo Walcott
Pagodia bia Walcott
Pagodia dolon Walcott
Anomocarella carme Walcott
Ptychaspis ceto Walcott
Ptychaspis cadmus Walcott
Ptychaspis calchas Walcott
Ptychaspis sp. undt.
Menocephalus? depressus Walcott
Dikelocephalus? brizo Walcott

Another small lot, collected 7 to 8 miles, 11 to 13 kilometers, east of Ch'au-mi-tién, seems to belong here, although no section was measured at that place; it contains:

Illænurus canens Walcott
Ptychaspis calyce Walcott
Ptychaspis campe Walcott

Fossils are comparatively rare in the upper portion of the Ch'au-mi-tién limestone, but small numbers of them were found within 50 feet, 15 meters, of the top, in certain light gray layers, and occasionally in the dark bluish strata. Several lots from this horizon, all taken in the vicinity of Ch'au-mi-tién, furnished a combined list of the following species:

Billingsella pumpellyi Walcott
Orthis (*Plectorthis*) *pagoda* Walcott
Orthis (*Plectorthis*) *kayseri* Walcott
Platyceras clytia Walcott
Orthotheca cyrene Walcott
Ptychaspis acamus Walcott
Ptychaspis ceto Walcott
Ptychaspis sp. undt.
Anomocarella baucis Walcott
Bathyurus?

From the stream gravels used in making the railroad grade at Tsi-nan-fu, we obtained *Plectorthis linnarssoni* Kayser and *Obolus* sp., which indicate that these erratics were derived from approximately the same horizon as the list just enumerated.

In the Sin-t'ai District.

Stratigraphy.—The classification of the Kiu-lung group into three separate divisions is not appropriate for this district, in spite of the fact that the general paleontologic horizons of the Ch'ang-hia area are recognized here with ease. The black oolite is much reduced in thickness, and is largely replaced by shales. The Ku-shan shale is thicker and carries fossils which belong to the Ch'ang-hia and Ch'au-mi-tién formations, respectively, in its upper and lower portions. The Ch'au-mi-tién limestone alone retains the general character noted in the first area studied, but

its base is somewhat shifted. Thus, the Kiu-lung, which in the Ch'ang-hia district is a group composed of three formations, is in the Sin-t'ai district a consistent formation, containing members of limestone and shale which are of local occurrence only.

In the region about Yen-chuang, the prominent features of the section are as follows, reading from the top downward:

5. Uppermost limestone member.................................. 250–300 feet, 75–90 meters.
(Thin-bedded gray limestones, often conglomeratic, which represent most of the Ch'au-mi-tién formation.)
4. Upper shale member.. 100–120 feet, 30–36 meters.
(Green shales, usually in two layers separated by a thin limestone. The shales themselves are sometimes soft and argillaceous, but at other levels are hard and slaty, containing numerous limestone nodules.)
3. Middle limestone member...................................... 120–150 feet, 36–45 meters.
(Light gray dense or granular limestone, usually mottled with ocher. Represents the upper one-third of the Ch'ang-hia limestone.)
2. Lower shale member.. 100–170 feet, 30–50 meters.
(Soft green shales containing thin strata and nodules of dense limestone.)
1. Lowest limestone member...................................... 100–180 feet, 30–54 meters.
(Dark gray limestone, much of it oolitic and thick-bedded. The basal layers are frequently slabby and more or less replaced by green shales and calcareous sandstone. Fossiliferous layers were found at frequent intervals from bottom to top of this series, and they may be expected at almost any horizon in it.)

Beginning with the base of these sediments as they succeed the Man-t'ou shales, we find in the mountain northeast of Sin-t'ai-hién a sandy, gray limestone, which contains several strata of calcareous sandstone. This arenaceous member averages 40 feet, 12 meters, thick, and yields numerous specimens of a single brachiopod (*Obolus obscurus*). The same lithologic horizon was found again in the Kiu-lung-shan, southwest of Yen-chuang.

Above the sandy member in the Sin-t'ai section follow 330 feet, 105 meters, of rather thin-bedded gray limestone, which is largely oolitic and frequently very dark in color, thus agreeing essentially with the Ch'ang-hia oolite. The uppermost strata are thin-bedded light gray limestones of fine texture, dense, and mottled with ocher. This phase, however, is by no means constant. About 4 miles north of Sin-t'ai, and only 1.5 miles, 2 kilometers, from the section just mentioned, a member of soft green shale is found occupying the central portion of these limestones to a thickness of about 50 feet, 15 meters. This shale contains flattish nodules of limestone which are exceedingly rich in fossils. A similar condition was noted near Kau-kia-p'u and in the Kiu-lung-shan, where 30 feet, 9 meters, of the shales occur only 20 feet, 6 meters, below the summit of the limestones, which are regarded as correlative with the Ch'ang-hia formation. Well-preserved specimens of Middle Cambrian trilobites and brachiopods abound in two or three seams of limestone which interrupt the shales.

The lower limestones and shales are followed by a second argillaceous member, in which green nodular shales alternate with slabby blue limestones, locally conglomeratic, through a vertical range of about 150 feet, 45 meters. In the upper part of this member there are greenish platey limestones, which produce talus slopes covered with hard thin plates of rock. These were known in the field as the "swallow slates," from the fact that the weathered surfaces expose large numbers of pygidia of the trilobite *Drepanura premesnili* Bergeron, which bear a fanciful resemblance to swallows in flight.

The remainder of the Kiu-lung group is composed of a variable succession of limestones having a thickness of over 500 feet, 150 meters. Although they are mostly thin-bedded and often slabby, two relatively

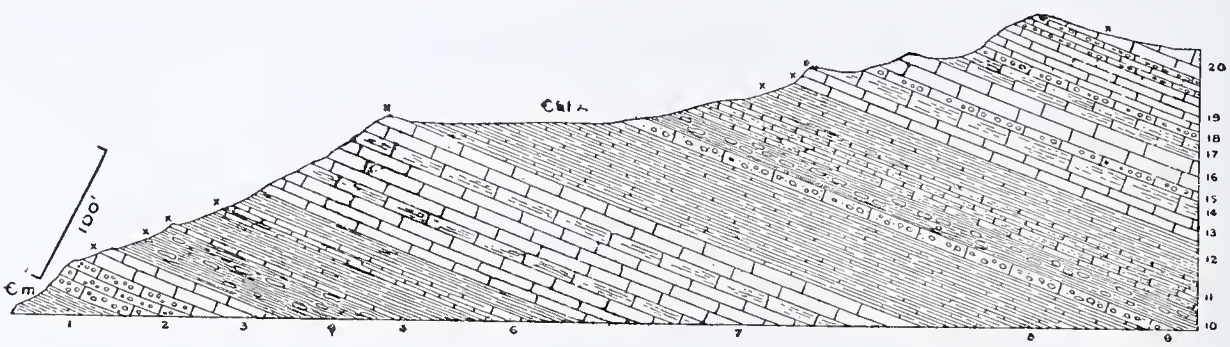


FIG. 10 (Blackwelder).—Yen-chuang, Shan-tung. Section of Kiu-lung formation in Kiu-lung-shan. 1 = Man-t'o shales; 2 = dark limestone, partly oolitic; 3 = dense gray limestone; 4 = nodular green shale; 5 = dense gray limestone; 6 = gray shale and slabby limestone; 7 = thin-bedded dense gray limestone; 8 = green calcareous shale; 9 = conglomeratic limestone; 10 = nodular green shale; 11 = slabby blue limestone; 12 = shaly limestone and gray shale; 13 = black limestone; 14 = slaty gray limestone; 15 = conglomeratic limestone; 16 = massive gray limestone; 17 = thin-bedded gray limestone; 18 = red conglomeratic limestone; 19 = dark gray limestone, locally conglomeratic; 20 = massive gray limestone.

massive members produce cliffs. Dense hard blue-gray limestones predominate over the granular layers. Conglomeratic strata, which occur at many horizons, are identical in appearance with both the red and the brown phases observed near Ch'au-mi-tién. In the uppermost beds of the formation one often finds concentric structures which are developed by weathering into features which, in size and appearance, are not unlike transverse sections of cabbages. Although they have the aspect of concretions, they are not composed of any foreign material; they are an integral part of the limestone itself. Similar structures are known from the Algonkian limestones of Montana in the northwestern United States.

In these upper limestones fossils are only moderately abundant, and are usually not well preserved. Those which are present agree essentially with the faunas of the Ch'au-mi-tién formation in the type locality.

Fossils from the lower limestone.—In the mountains southwest of Yen-chuang, a small lot of fossils was collected from the greenish gray

limestone, only 15 feet above the brown shale, which we regard as the top of the Man-t'o formation. This comprises:

Globigerina? mantoensis Walcott	*Agraulos divi* Walcott
Micromitra pannula ophirensis Walcott	*Anomocare? butes* Walcott
Acrotreta pacifica Walcott	*Dolichometopus* sp. undt.

About 30 feet, 9 meters, higher, in the same section, a brownish, sandy limestone, rich in mica, yielded numerous specimens of a single brachiopod, *Obolus obscurus* Walcott.

Another small lot comes from a horizon believed to be almost equivalent to the last, the locality being the mountain 3 miles northeast of Sin-t'ai-hién. Here four species of trilobites occur, some of them abundantly:

Agraulos dirce Walcott	*Anomocare latelimbatum* Dames
Anomocare? butes Walcott	*Ptychoparia tolus* Walcott

As we go upward in the series, the next fossiliferous horizon is at the base of the dark cliff-making oolite, as exposed 3 miles, 5 kilometers, southwest of Yen-chuang. The layer is of variable thickness, but here

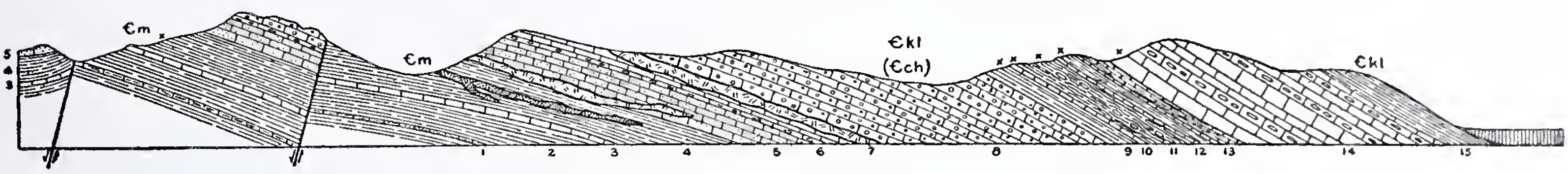


FIG. 11 (Blackwelder).—Kau-kia-p'u, Shan-tung. Section of faulted Cambrian strata in the ridge northwest of the village. 1 = slabby yellow limestone; 2 = red shale; 3 = olive-gray limestone; 4 = brown micaceous shale with basalt sheet; 5 = sandy greenish limestone with porphyry sheet; 6 = gray conglomeratic limestone; 7 = porphyry sheet; 8 = dense gray limestone, partly oolitic; 9 = soft green shale; 10 = gray limestone; 11 = green shale with limestone nodules; 12 = gray crystalline limestone; 13 = thin gray limestone and shale; 14 = dense gray limestone, locally conglomeratic; 15 = gray and green shale.

the base is 80 or 90 feet, 25 meters, above that of the Kiu-lung group. The stratum in which the specimens were found is a dark red limestone, only a few centimeters in thickness, and the remains are all fragmentary:

Micromitra labradorica orientalis Walcott	*Anomocare decelus* Walcott
Agraulos abaris Walcott	*Anomocare minus* Dames

In a gray oolitic layer, lying immediately upon this red limestone and only a few feet higher in the series, a somewhat more comprehensive assemblage of forms occurred, but among them there is only one which appears also in the red layer below. The list includes:

Obolus (*Lingulella*) *damesi* Walcott	*Agraulos dolon* Walcott
Obolus (*Lingulepis*) *eros* Walcott	*Ptychoparia titiana* Walcott
Agraulos abaris Walcott	*Ptychoparia* (*Liostracus*) *thraso* Walcott

We have no fossils from the remaining upper portion of what we have called the lowest limestone member.

Fossils from the lower shale.—At the base of the lower shale-member fossils appear in great profusion, being especially well preserved in the

numerous nodules and thin seams of limestone embedded in the shales. The cephala and pygidia of *Agnostus* and several larger trilobites are so abundant here that a considerable proportion of the rock is composed of their remains. The collections from the lowest stratum of this member, about 4 miles north of Sin-t'ai-hién, yield the following:

Acrothele rarus Walcott
Orthotheca delphus Walcott
Agnostus chinensis Dames
Agnostus kushanensis Walcott
Anomocare alcinoe Walcott
Anomocarella albion Walcott
Anomocarella chinensis Walcott
Dolichometopus deois Walcott
Dorypyge richthofeni Dames

In the mountains southwest of Yen-chuang the basal layers of these shales preserve a rich fauna, having at least four species in common with the locality farther south, which has just been mentioned. The majority of these were found, as in the former case, in nodules of dense gray limestone:

Protospongia chloris Walcott
Acrotreta pacifica Walcott
Platyceras chronus Walcott
Hyolithes cybele Walcott
Orthotheca delphus Walcott
Agnostus chinensis Dames
Anomocarella chinensis Walcott
Arionellus alala Walcott
Dolichometopus alceste Walcott
Dolichometopus deois Walcott

Near this place a larger collection was secured from numerous calcareous nodules, not only at the base of this shale, but also ranging through a vertical thickness of 20 to 30 feet, 6 to 9 meters. The following list, therefore, includes not only many of the previous list, but some species of slightly later age:

Protospongia chloris Walcott
Acrotreta pacifica Walcott
Obolus minimus Walcott
Obolus (Lingulella) damesi Walcott
Obolus (Westonia) blackwelderi Walcott
Platyceras chronus Walcott
Hyolithes cybele Walcott
Orthotheca cyrene dryas Walcott
Agnostus chinensis Dames
Agraulos divi Walcott
Arionellus agonius Walcott
Dolichometopus derceto Walcott
Dolichometopus deois Walcott
Dorypyge richthofeni Dames
Dorypyge bispinosa Walcott
Anomocare latelimbatum Dames
Anomocare temenus Walcott
Anomocare biston Walcott
Anomocare daunus Walcott
Anomocarella albion Walcott
Anomocarella chinensis Walcott
Anomocarella contigua Walcott
Ptychoparia tellus Walcott
Menocephalus sp. undt.

Fossils from the middle limestone.—Much of the middle limestone member seems to be without fossils, but here and there in the section certain layers yield them plentifully. All of the collections from this member come from the mountain 3 or 4 miles, 5 or 6 kilometers, southwest of Yen-chuang. In the lower layers we found a fauna closely allied with the preceding forms, and consisting of:

Acrotreta shantungensis Walcott
Obolus (Lingulella) chinensis Walcott
Hyolithes cybele Walcott
Anomocarella chinensis Walcott

Near the top of the limestone there is a well-preserved assemblage of trilobites, with a few other forms characterized by an abundance of *Damesella*, two species, and *Acrotreta pacifica*. These occur in several different localities which are not, however, widely separated. This fauna has no species in common with the last or with the next succeeding fauna. The list comprises:

Acrotreta pacifica Walcott
Agraulos acalle Walcott
Arionellus ajax Walcott
Damesella blackwelderi Walcott
Damesella bellagranulata Walcott
Blackwelderia alastor Walcott
Teinistion alcon Walcott
Teinistion typicalis Walcott
Ptychoparia (*Liostracus*) *tutia* Walcott
Pterocephalia asiatica Walcott

Fossils from the upper shale.—Although not so rich in fossils as the lower shale, the upper shaly member gives us some very interesting and characteristic species. Most of the specimens are found in thin platey limestones, interbedded with light gray shales not far below the top of the member. The fossils occur on the weathered surfaces of these hard ringing slabs. The most striking and one of the commonest species here is *Drepanura premesnili* Bergeron. The large dentate pygidia of *Blackwelderia cilix* Walcott and the smaller ones of *Blackwelderia sinensis* (Bergeron) are also characteristic of this horizon. The entire list from the vicinity of Yen-chuang is as follows:

Acrothele minuta Walcott
Dicellomus parvus Walcott
Obolus (*Westonia*) *blackwelderi* Walcott
Agnostus chinensis Dames
Agnostus kushanensis Walcott
Stephanocare richthofeni Mönke
Stephanocare sinensis (Bergeron)
Blackwelderia sinensis (Bergeron)
Drepanura premesnili Bergeron
Drepanura ketteleri Mönke
Ptychoparia? bromus Walcott
Ptychoparia tenes Walcott
Liostracina krausei Mönke
Redlichia finalis Walcott
Redlichia sp. undt. Walcott
Shantungia spinifera Walcott

Fossils from the upper limestone.—The uppermost member is very nearly equivalent in age to the Ch'au-mi-tién formation of previous sections, although it is somewhat thinner. Fossils occur in it at several horizons. The oldest fauna of this member was found in a blackish gray, partly oolitic limestone, immediately overlying the upper green shale. Although not more than 10 feet, 3 meters, vertically, from the last, this horizon yielded no species common to the two strata. Here we find:

Billingsella pumpellyi Walcott
Pterocephalia busiris Walcott
Dikelocephalus? baubo Walcott
Ptychoparia batia Walcott
Ptychoparia (*Proampyx*) *burea* Walcott

Sixty feet, 18 meters, above the base of the uppermost limestone member a gray crystalline layer yields:

Chuangia nitida Walcott
Ptychoparia batia Walcott
Anomocare bergioni Walcott

About 200 feet, 60 meters, higher, in the same series, *Damesella blackwelderi* was found in some numbers.

The only horizon in which fossils seem to be plentiful is 50 to 75 feet, 15 to 23 meters, below the top of the member. At this horizon a granular gray limestone contains a varied fauna, which is allied, by the presence of three species in both regions, to that from the upper portion of the Ch'au-mi-tién limestone in the type locality. This fauna includes:

Orthis (Plectorthis) doris Walcott
Orthis (Plectorthis) linnarssoni Kayser
Orthis (Plectorthis) kayseri Walcott
Syntrophia orientalis Walcott
Hyolithes daphnis Walcott
Orthotheca cyrene Walcott
Anomocare? bianos Walcott
Dikelocephalus? baubo Walcott
Ptychaspis cacus Walcott
Ptychaspis callisto Walcott
Ptychaspis calyce Walcott
Ptychaspis ceto Walcott
Ptychoparia batia Walcott
Solenopleura beroe Walcott

A single small and imperfect specimen of *Orthoceras* sp. was discovered in the uppermost layers of the Ch'au-mi-tién limestone near Yen-chuang. The presence of this genus indicates close approximation of the Ch'au-mi-tién to the Ordovician.

Vicinity of T'ai-an-fu.

Scattered exposures of the Kiu-lung strata were examined during our journey along the main road from Ch'ang-hia to Sin-t'ai and thence to Po-shan. Some of these show individual peculiarities worthy of mention.

About 1 mile, 1.5 kilometers, west of the city of T'ai-an-fu, the hill marked by a small pagoda is composed entirely of the lower limestones of the Ch'au-mi-tién formation. The hill is surrounded by a broad plain of alluvial material, and is thus cut off from the granitic exposures north of it. On this account stratigraphic connections were not visible, but fossiliferous layers in the limestone furnished an ample array of species for the purpose of correlating the strata with the proper horizons in other districts. From strata 20 to 30 feet, 6 to 9 meters, below the top of the hill we secured fossils whose nearest allies are those from the lower part of the Ch'au-mi-tién limestone, both in the type locality and in the region east of T'ai-an-fu as well. The list of species from this pagoda hill includes:

Obolus matinalis Hall
Obolus (Westonia) sp. undt.
Orthis (Plectorthis) pagoda Walcott
Syntrophia orientalis Walcott
Scenella sp. undt.
Platyceras pagoda Walcott
Straparollina circe Walcott
Orthotheca sp. undt.
Cyrtoceras cambria Walcott
Illænurus canens Walcott
Illænurus dictys Walcott
Menocephalus? depressus Walcott
Pagodia bia Walcott
Pagodia lotos Walcott
Pterocephalia busiris Walcott
Ptychaspis ceto Walcott
Ptychoparia dryope Walcott
Solenopleura belus Walcott

Ten miles east of T'ai-an-fu, north of the main cart road and just east of the Wön-ho, most of the Cambrian section is exposed in a low group of hills. As the Man-t'o shales occur in the lowlands, their outcrop and their contact with the gneiss are largely obscured by soil. The summits are capped by 100 feet, 30 meters, of Ch'au-mi-tién limestone. Beneath this appear green and gray calcareous shales, sometimes platey near the top and nodular below, making a total thickness of nearly 200 feet, 60 meters. The platey beds carry the "swallow trilobite" fauna already mentioned, and thus afford an excellent basis for the correlation of this section with others. The shales rest upon 125 feet, 37.5 meters, of gray mottled limestones, which are similar to the upper layers of the Ch'ang-hia limestone, but the lower portion of that formation seems to be represented by the green shales and thin-bedded limestones which form the very base of the slope and are obscured by cultivated terraces. This section resembles those observed in the Yen-chuang region more than any others, but the shales are even more prominent here than in that district.

In examining these outcrops we found a copious representation of the fauna of the upper green shale, as it occurs in the Yen-chuang region; here the fossils are found in slabby limestone and green shales, immediately beneath the massive strata which resemble the Ch'au-mi-tién limestone. From this material five species have been identified, all but the first being common, as well, to the fauna from Yen-chuang:

Straparollina sp. undt.
Agnostus chinensis Dames
Blackwelderia sinensis (Bergeron)
Blackwelderia cilix Walcott
Drepanura premesnili Bergeron

SOUTH OF PO-SHAN.

Fifteen miles, 24 kilometers, south of Po-shan, near the village of Meï-yü-shan, the hills on the east side of the valley and thence northward to the vicinity of Po-shan expose a complete sequence of the Sinian system. In the cursory examination which we were able to make, we did not discover any important differences between this and the succession at Yen-chuang. The Ch'ang-hia limestone is prominent in the cliffs, but a member of green shale is included in its upper portion, as in the Kiu-lung-shan.

TSI-NAN FORMATION.

One of the most widely distributed formations in China is the one to which von Richthofen gave the name "Kohlenkalkstein," or Coal-limestone. From the fact that it always occurs beneath the coal-bearing strata wherever they appear, and bears considerable resemblance to the Carboniferous limestone of the Yang-tzï valley, he inferred that it was probably of the same age.* Being unsuccessful in his search for fossils

* China, von Richthofen, vol. II, pp. 226 and 319.

in these limestones, he was not in a position either to verify or to set aside his hypothesis. During our surveys in Shan-tung we secured sufficient, although meager, paleontologic evidence of the fact that the so-called "Kohlenkalk" is of Ordovician age;* furthermore, it is a conformable member of the Sinian system, and is separated from the Carboniferous by an unconformity.

We found the Ordovician limestone broadly exposed in the northwestern part of the Shan-tung mountains; near Ts'ai-kia-chuang and in the hills southeast of that place; in several localities between Sin-t'ai and Yen-chuang, and in the region around Po-shan. Doubtless it is exposed in many other districts in the province. The hills immediately south of Tsi-nan-fu are composed of this limestone.

Throughout central Shan-tung, as far as our observations extended, two members of the Tsi-nan limestones may be recognized. The lower is a variable sequence of light-colored argillaceous limestones or dolomites and thin shales. The upper member, which comprises about nine-tenths of the formation, is a brown dolomitic limestone of uniformly fine texture, and occurs in massive strata.

In the Ch'ang-hia District.

Stratigraphy.—Both divisions of the Tsi-nan formation are to be found in the northern part of this area. The lower member is mainly calcareous, but is characterized by a large percentage of earthy and dolomitic material. The rocks are buff, gray, and even ashy white in color. Certain layers are soft and shaly, while others feel distinctly sandy to the touch and yet indicate by their habit of weathering that they are soluble rocks; upon microscopic and chemical examination the latter prove to be crystalline dolomites. Slabby earthy limestones constitute the major part of the formation. No fossils were found anywhere in this member.

The upper limestone member overlies the shaly strata without visible interruption. With very little variation, it consists of moderately thick beds of dark dolomitic limestone, which has a brownish cast of color on freshly broken surfaces; but develops on exteriors a decidedly blue-gray tint. It is aphanitic in texture and breaks with an irregular fracture, which does not follow any definite lines of cleavage. In many cases where the rock has suffered slight deformation, short gash-veins of white calcite,

* Several Ordovician fossils were described by Frech in 1895 from Sinian limestone near Nan-king (Neues Jahrb. für Mineralogie, 1895, p. 47). Lorenz has recently published a statement of the Ordovician age of the Tsi-nan limestone based on fossils found by him south of Tsi-nan-fu in 1902. Beiträge für Geologie und Paleontologie von Ostasien, I Teil, Marburg, 1905, by Dr. Phil. Theo. Lorenz. The fossils which we collected from Ordovician rocks have been determined by Dr. Stuart Weller, whose report will be found in the volume on paleontology.

conspicuous because of their color, traverse the rock. Of exceptional occurrence are certain scattered strata of earthy gray limestones and partings of gray calcareous shales. These, however, constitute but a very small part of the whole formation.

Fossils in the Tsi-nan formation.—Fossils are rare at any horizon and are usually entirely absent. Where found at all they occur as siliceous or calcareous casts upon the weathered surfaces, or are visible in section only. When the rock is broken the fracture disregards the outlines of the fossils, and it is therefore futile to search for them, except where they have been etched out by weathering. The only identifiable fossils found in this area are referable to the Ordovician period. About 700 feet, 210 meters, above the base of the Tsi-nan formation imperfect specimens of *Orthoceras* sp. were found. Similar forms were collected at indeterminate horizons in the hills southwest of Tsi-nan-fu. A brachiopod related to *Strophomena* was obtained at one of these localities.

In the Sin-t'ai District.

Stratigraphy.—So uniform is the main body of the Tsi-nan formation that little need be said of its facies in the Sin-t'ai district as contrasted with that of the Ch'ang-hia district. The lower member exhibits less variation than before, being a fairly constant succession of ashy white limestones, with local layers of crystalline dolomite and gray calcareous shales. A minor structural peculiarity of these gray limestones serves to distinguish them from other Shan-tung formations in almost all situations. The rock is crossed by numerous cracks or "blind joints" in two systems, which are perpendicular to each other, and the agents of weathering, etching along these planes of weakness, divide the surface into little squares, usually about 1 centimeter in breadth. This checkered appearance is one of the most prevalent characteristics of the lower Tsi-nan limestones.

Fossils in the Tsi-nan.—The massive upper limestone, which outcrops at Ts'ai-kia-chuang, in the hills south of Sin-t'ai and around Yen-chuang, needs no further description. After painstaking search, fossils were found in the first locality, not far below the top of the formation; they included undetermined gastropods, *Orthoceras*, and a trilobite (*Asaphus?*) which could not be extricated from the large slab of limestone in which it was embedded. Loose rubble resting upon these outcrops near Ts'ai-kia-chuang yielded the following imperfectly preserved Ordovician forms:

Brachiopod (*Orthis?* or *Dalmanella?*)
Lophospira sp. undt.
Gastropod (*Maclurea* or *Helicotoma*)
Orthoceras sp. undt.
Asaphus? sp.

South of the Siau-wön-ho, in the longitude of Sin-t'ai-hién, two species of similar character were collected from massive limestone estimated to be 300 to 500 feet, 90 to 150 meters, below the top of the Tsi-nan formation:

Orthoceras sp. undt. *Gastropod* undt.

Equally imperfect and rare fossils were observed at several other localities in east China, viz, at Po-shan and Yen-chuang, Shan-tung, and at the T'ang-shan coal-mines in Chï-li.

IN THE PO-SHAN DISTRICT.

As exposed near Po-shan the Tsi-nan formation presents no new peculiarities. The city itself stands upon the eroded surface of the uppermost layers of the Tsi-nan limestone. Immediately to the southeast a normal fault drops the formation below the surface and thus preserves a portion of the overlying coal-measures. The limestone soon reappears, however, from beneath the Po-shan strata, and is exposed in a nearly horizontal position for a distance of about 10 miles, 16 kilometers, south of the city.

IGNEOUS ROCKS ASSOCIATED WITH THE SINIAN SYSTEM.

We saw no evidence of volcanic activity which was contemporaneous with the deposition of the Sinian rocks. All the igneous rocks occur as dikes and sills, and, except for the obvious fact that they are younger than the terranes which they penetrate, there is nothing from which trustworthy conclusions as to their age can be drawn. However, it is notable that most of these dikes are petrographically similar to intrusions in the Permo-Carboniferous system, and it is therefore probable that the dikes which cut the Sinian rocks date from the same period of volcanic activity.

Sills and small laccolitic masses of hornblende-syenite-porphyry are frequently found in the lowest beds of the Man-t'o formation. The soft shales probably yielded readily to the pressure of the intruding magma as it was forced into the sedimentary rocks. In the mountain east of Ch'ang-hia, the Man-t'o shale contains several sheets of a gray-green syenitic lava, the phenocrysts of which were formerly cruciform crystals of hornblende, but are now replaced by calcite and other alteration products. These sheets range in thickness from a minimum of 1 foot up to 25 feet. Two dikes, respectively 5 and 12 feet across, rise higher in the Sinian, the latter cutting the Ch'ang-hia oolite a few miles northeast of the village of the same name. Like the sills, they too are syenitic.

In the Sin-t'ai district, rocks bearing a general similarity to these were seen in the basal Man-t'o shales, and also near the top of that formation. One and one-half miles, 2 kilometers east of Kau-kia-p'u there is a laccolitic

intrusion, 100 feet, 30 meters, long and 12 feet, 3.6 meters, thick, which consists of a different rock. The phenocrysts are of alkali feldspar and hornblende, set in a ground-mass composed of quartz and feldspar; a dacite, in the old system of nomenclature. The brown shales were not notably metamorphosed at their contact with this porphyry, but the planes of cleavage in the shales were observed to be parallel with the surface of the laccolite for a distance of about 2 feet. This was brought out most clearly near the edges of the intrusion, because there the cleavage due to igneous influences was plainly discordant with horizontal planes such as are commonly developed by clays during consolidation.

About half-way between Kau-kia-p'u and Yen-chuang another dacitic sill, nearly 100 feet, 30 meters, thick, occupies the contact between the lower and the upper members of the Tsi-nan limestone. Even in the case of so thick a sheet, the phenomena of contact-metamorphism were not prominent. As we approached the Yen-chuang coal-field, with its abundant volcanic rocks, we crossed several dikes of buff-brown feldspar-porphyry. One mass of this rock, a few yards across, is intruded along the fault contact in the north end of Hu-lu-shan butte. Another cuts the Kiu-lung and Tsi-nan limestones 2.5 miles, 4 kilometers, southeast of Yen-chuang. This dike is 30 to 40 feet, 9 to 12 meters, wide and more than a mile in length. Such rocks decompose more rapidly than the limestones into which they are intruded, and as weathering proceeds they come to occupy cols, swales, and gullies, according to their situation.

In the alluvial plain north of Tsi-nan-fu several conical hills stand out in conspicuous isolation. They are composed of a coarse-grained hypersthene-gabbro (norite) of black-green color; the rock contains olivine also. The roundish areas of outcrop suggest that the hills may be old volcanic necks, but, if so, the ejectamenta of the volcanoes have long since been carried away in the degradation of the region, for no tuffs or lavas are visible there at present. We saw nothing by which we could determine the age of the gabbro relative to the Tsi-nan dolomite, which forms the hills to the south.

The only dike of igneous rock found in the limestone hills near Tsi-nan-fu occurs near the border of the plain, 2.5 miles, 4 kilometers, west-southwest of the city. At first sight it has the appearance of a fine-grained pink granite, but upon microscopic examination it proves to be a quartzose syenite-porphyry; it has a finely crystalline ground-mass, composed of sodic feldspars and quartz, with small phenocrysts of hornblende and feldspars like those of the ground-mass. The composition of this rock is such as to indicate that it is not genetically related to the hypersthene-gabbro just mentioned.

PRE-CARBONIFEROUS UNCONFORMITY.

We observed no rocks of Silurian, Devonian,* or Lower Carboniferous age in Shan-tung. The coal-bearing series lies in all cases directly upon the surface of the Tsi-nan limestone. We found the two systems in adjacent outcrops at Ts'ai-kia-chuang, on both sides of Yen-chuang, and at Po-shan. In the last two of these places the actual contact was well exposed, revealing the fact that, although the coal-measures agree in dip and strike with the underlying limestone, as if the succession were conformable, there is a very distinct erosion unconformity. As stated elsewhere in this report, the rocks of this region suffered no considerable amount of deformation during the Paleozoic era, and therefore unconformity of bedding between the two Paleozoic formations is not to be expected.

In the shallow canyon of the Siau-fu-ho, the basal shales of the Po-shan series may be clearly seen in contact with the Ordovician limestone. The surface of the latter is irregular and cavernous, the cavities and prominences being rounded and tufaceous, like the exteriors of limestone outcrops which have long undergone terrestrial weathering. This irregular surface is filled in and covered by evenly bedded green and blackish shales. They completely fill the old solution cavities, surround the protuberant points, and overspread the whole contact as they grade upward into the higher strata of the Po-shan series. The logical inference from these relations is that the Tsi-nan limestone emerged, without notable warping, at some time prior to the Po-shan epoch of the Carboniferous. It then suffered weathering and, doubtless, a limited amount of erosion. At the beginning of the Po-shan epoch, presumably attending a slight subsidence of the land, the sea or some other body of quiet water encroached over the weathered surface of the limestone. Fine clays were washed and sifted into the caverns and minor recesses, completely filling them and cementing the superficial limestone rubble into an agglomerate.

Since the limestones were not folded or appreciably inclined before the period of erosion, the dip of the subsequently deposited shales is concordant. The character of the contact is amply sufficient to prove an unconformity. The absence of Silurian, Devonian, and Lower Carbon-

* Lorenz states (*loc. cit.*, p. 16) that a great period of sedimentation began in the Upper Devonian and continued on through the Carboniferous. The evidence which he furnishes seems to us quite insufficient to prove the statement. The lowest fossiliferous beds above the Ordovician limestone are not older than uppermost Lower Carboniferous according to Frech, who has recently reviewed the fossils brought by von Richthofen from Po-shan and by Lorenz from the same locality. He considers them to be of late lower Carboniferous age. (Neues Jahrb. für Min., 1895, p. 47.) The barren beds beneath are 100 to 300 feet thick, but form a continuous sequence with the fossil-bearing strata, and at their base are fine shales which lie in caverns and crevices in the limestone.

iferous series from Shan-tung indicates that the interval of erosion may have included all of those periods, and thus be worthy of rank as an unconformity of the first magnitude. It is possible, however, that sedimentation may have continued long after Ordovician time, and that the resulting rocks were subsequently removed by erosion, in all the localities thus far examined.

CARBONIFEROUS SYSTEM.

The younger consolidated rocks which we encountered on our journey in central Shan-tung belong in part to the Pennsylvanian (Upper Carboniferous) and in part, probably, to a later period (Fig. 12). At the base lies a series of coal-bearing shales and sandstones, near the top of which there occur volcanic flows, tuffs, and intrusions in varying amount.* These are followed by red and gray sandstones, shales, and conglomerates, which are believed to be of distinctly later age. For the coal-measures we propose the name "Po-shan series," on account of the important position which the city of that name has long maintained in the production of coal and in the manufacture of clay wares, the materials for which are secured from the coal-measures in that vicinity.

PO-SHAN COAL-BEARING FORMATION.

Exposures of the coal-measures were examined in the vicinity of Ts'ai-kia-chuang, Yen-chuang, and Po-shan, and they are known to occur also at Weï-hién,† I-chóu-fu,‡ and several other places in the province.

IN THE SIN-T'AI DISTRICT.

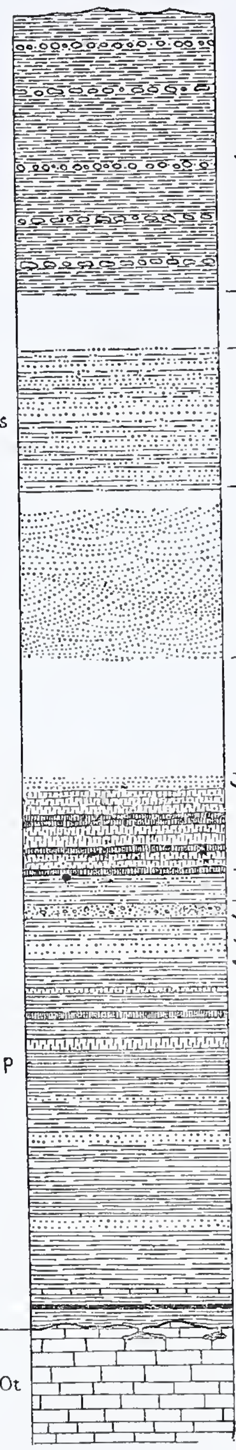
Stratigraphy.—The Po-shan rocks were first seen under somewhat unfavorable conditions, 2 miles, 3 kilometers, northeast of the village of Ts'ai-kia-chuang. Yellow, black, and gray shales and quartzose sandstones are exposed in several shallow gullies, but not broadly or continuously. The thickness of the strata included in these shales and sandstones was estimated at something more than 1,000 feet, 300 meters. At many horizons the shales contain clay-ironstone nodules, but unfortunately these are not productive of fossils, as are similar nodules in certain parts of the United States.

The only recognizable organic remains which we found were some imperfectly preserved plants, occurring in a coarse white sandstone, several hundred feet above the coal seam, which is now mined. While examining this same exposure more than thirty years ago, von Richthofen collected specimens of the fossil plants. Professor A. Schenk, in his

* Lorenz regards the tuffs and other volcanics as Permian (*loc. cit.*, p. 18).

† See von Richthofen, vol. II, page 210.

‡ Ibid., page 184.



			Feet.	Meters.	
Permo-Mesozoic.	Sin-t'ai series.	PMs	500+	150+	Massive red clays with interstratified layers of lime nodules and coarse conglomerate.
			100±	30±	Not observed.
			250±	75±	Gray sandy shale and sandstone.
			300±	90±	Dull red cross-bedded sandstone.
			200±	60±	Not observed.
Upper Carboniferous (Pennsylvanian).	Po-shan series.	Cp	20	6	Purple-brown sandstone.
			160	48	Stratified green tuffs and basalt flows.
			60	18	Red sandy shale.
			25	8	Gray and red conglomeratic sandstone.
			35	10	Red sandy shale.
			30	9	Gray and maroon sandstone.
			140	42	Yellow and purple shales with green stratified tuffs and basalt flows.
			50	15	Black and maroon shales.
			100	30	Yellow and brown shale and sandstone.
			55	17	Gray and yellow shale, green sandstone.
			35	10	Gray shale.
			40	12	Maroon shale.
			25	8	Brown graywacke sandstone.
			180	54	Brown, yellow, and gray shale, with coal and limestone.
					Unconformity.
Ordovician.	Tsi-nan limestone.	€Ot			Dark dolomitic limestone.
	Total		2,305	692	

FIG. 12.—SECTION OF CARBONIFEROUS AND LATER FORMATIONS NEAR YEN-CHUANG, SHAN-TUNG.

discussion of the fossil plants submitted to him by von Richthofen, says of these specimens from "Tsing-ko-tschwang" (Ts'ai-kia-chuang): "That they belong to the Carboniferous is revealed at the first glance."* This opinion is in accord with the close resemblance of the strata to those at Yen-chuang, which have been even more positively identified as Carboniferous by means of well-known animal fossils.

If one may judge by the positions of the abandoned mines, which are scattered over the plain, the coal itself occurs at several horizons. Since the whole series is inclined 30° to 40° to the southwest, the mines would lie approximately in a row if only a single vein had been exploited. No igneous rocks were observed in this locality.

A small exposure of the basal Carboniferous shales appears on the south side of the Wön-ho, 5 miles, 8 kilometers, south of Sin-t'ai-hién. Although they are here adjacent to the Ordovician limestone, no opportunities for studying the contact of the two formations were afforded. The rock surface dips under the alluvium of the river flat, thus concealing the coal, if it exists here at all.

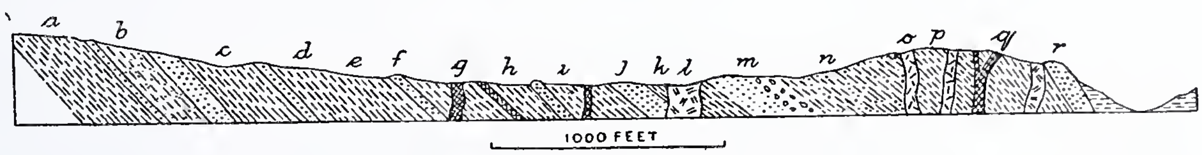


FIG. 13 (Blackwelder).—Yen-chuang, Shan-tung. Partial section of Po-shan (Carboniferous) and Sin-t'ai (Permo-Mesozoic), showing intrusive volcanic rocks. *a* = purple and yellow shales; *b* = gray sandy shale and sandstone; *c* = variegated shales; *d* = maroon shale and yellow sandstone; *e* = black shale; *f* = greenish sandstone and shale; *g* = basalt dikes and sills; *h* = yellow shale; *i* = variegated shales and gray sandstone; *j* = gray sandstone; *k* = red sandy shale: *l* = buff syenite-porphyry; *m* = gray and pink sandstone with local seams of conglomerate; *n* = red sandy shale; *o* = syenite-porphyry dikes; *p* = green stratified tuffs; *q* = basalt dike; *r* = dark gray sandstone.

In the vicinity of the town of Yen-chuang, the Po-shan formation occupies a large part of the plain east of the Wön-ho. The lowest rocks of the series are yellow, gray, and black shales with ocherous and gray sandstones in subordinate amount. Several coal-seams occur in the carbonaceous shales, 50 to 200 feet, 15 to 60 meters, above the base of the series, and are followed by more yellow shales, coarse sandstones, and nodular clays. Occasional green and purplish strata in the shales enliven the colors of the outcrops. Locally associated with the coal there is a black bituminous limestone, fragments of which, found lying on the coal-waste dumps near an abandoned mine, yielded specimens of well-known Carboniferous brachiopods. Richthofen found a similar fossiliferous limestone in the Po-shan coal-field, and was thus able to determine the age of the coal in Shan-tung.

* This identification has recently been disputed by Lorenz (*loc. cit.*, p. 19), but as he presents no new evidence regarding the "Tsing-ko-tschwang" flora, we accept Schenk's statement as the most reliable now available. Our own specimens were not identifiable.

The Yen-chuang field is characterized by abundant volcanic rocks of various kinds, occurring in the forms of dikes, sills, surface flows, and tuffs. Although the source of this material was not definitely located, it is thought that an irregular area of massive dolerites and pyroxene andesites, casually noted about 4 miles, 6.5 kilometers, southeast of the town, may represent the throat of the ancient volcano. In the immediate vicinity of this mass the Tsi-nan dolomite is metamorphosed into siliceous hornstones. The lava flows in the coal-measures themselves are basaltic and are now greatly weathered. They alternate with fine-grained greenish tuffs, yellow shales, and sandstones. The dikes and sills are composed not only of olivine basalt, but of brown and green hornblende-syenite-porphyries and buffish feldspar-porphyries. The largest dike of the latter seen was 70 feet, 21 meters, across, but most of the intrusions are relatively thin. As the coal-measures at Yen-chuang are exposed continuously for a distance of a mile or more, measured along the dip, and lie at an inclination which is rarely less than 25° and sometimes more than 40°, the total thickness of the formation, including the volcanics which are part of it, may exceed 2,000 feet, 600 meters.

Fossils from Po-shan formation.—The shales have yielded no fossils except the macerated remains of plants, and of these the majority are too imperfect for identification. Animal fossils were found at only two points, viz, near Yen-chuang in black limestone, and a few miles northwest of Sin-t'ai-hién. In the former locality a block of limestone was found in the material excavated from a shallow mine shaft, and its source could not be ascertained; there can be no doubt, however, that the stratum is within 100 feet, 30 meters, of the base of the Po-shan formation. Among the fossils contained in this block, Girty has found:

Chonetes sp.	*Squamularia* (cf. *Squamularia perplexa*)
Marginifera sp.	*Cleiothyris?* sp.

This fauna indicates that the formation is of Upper Carboniferous (Pennsylvanian) age. A few other forms were discovered in pebbles of Post-Carboniferous conglomerate (Wön-ho formation) near Ts'ai-kia-chuang. The species were preserved in chert nodules, which obviously had been derived from outcrops of Carboniferous limestone in the same region. Among the forms here found are:

Clavulina (?) sp.	*Chonetes* sp.
Fusilina sp.	*Dielasma* (?) sp.
Zaphrentis (?) sp.	*Phillipsia* sp.
Archæocidaris sp.	*Bythocypris* (?) sp.

The material was too scanty and too poorly preserved to permit of accurate identification.

In the Po-shan District.

Out of a number of small coal-fields in Shan-tung, that at Po-shan seems to be commercially one of the most important. Like all the others which we had an opportunity to examine, it owes its survival largely to normal faulting, which has lowered the soft Carboniferous strata down below the general base-level of the region. As it has already been described in considerable detail by von Richthofen,* it will not be necessary to discuss the geological conditions of the region at length. His observations were confirmed and supplemented by recognition of the Pre-Carboniferous unconformity, the significance of which was not perceived in his time. The Po-shan coal-measures are in the main like those at Yen-chuang, although the black shales appear in larger proportion, and the development of the volcanic rocks is not so conspicuous.

PERMO-MESOZOIC.

SIN-T'AI SERIES.

Under the name of Sin-t'ai series are grouped certain sedimentary rocks, which overlie the coal-bearing series, but which may or may not prove to be of the same general age.† Inasmuch as the contact of the two formations was not observed, the stratigraphic relation between them is not known.‡ Certain facts point to a relatively close connection between them. Both are intercalated with igneous flows which appear to be contemporaneous with the sedimentation. So far as observed, the two series coincide in dip as if conformably bedded and deformed at the same epoch. Another significant fact is found in the red color of the rocks, which suggests the Permian red beds of Europe and the United States, and indicates somewhat unusual climatic conditions similar to those which prevailed widely in the Permian.

In contrast to the lower, supposedly Permian, part of the sequence, the upper Sin-t'ai strata are characterized by coarse conglomerates. The succession above the Carboniferous is not unlike that observed by von Richthofen§ and Lóczy|| at Kuang-yüan-hién in Ssï-ch'uan, where both Permian and Jurassic are represented, the latter probably lying unconformably upon

* China, vol. II, pp. 201–208.

† The Jurassic coal-measures reported by Potonié from central Shan-tung (Futterer, Durch Asien, III, 1903) were not observed in the area covered by our survey.

‡ Von Richthofen found them lying above the coal-measures in the Sin-t'ai valley, but was unable to identify them with any terrane, either in Shan-tung or elsewhere. Lorenz reviews von Richthofen's description of the Sin-t'ai beds and assigns them to the time of dislocation which he associates with the Tertiary. The red sandstone, which we regard as the lower member of the Sin-t'ai beds, he classes with the Permian.

§ China, vol. II, p. 602.

|| Ergebnisse der Reise des Grafen Széchenyi, vol. II, p. 211.

the former, though with but slight difference of dip.* The occurrence of Jurassic coals in Shan-tung as well as Ssï-ch'uan adds to the value of this comparison, although they probably are not present in the Sin-t'ai district.

Within the area of our explorations, the Sin-t'ai series occurs in only three localities. It occupies most of the valley floor around the city from which it derives its name, extending 4 or 5 miles, 6 or 8 kilometers, south, 6 or 7 miles, 10 or 11 kilometers, west, and several miles southeastward. A smaller area is exposed 2 or 3 miles, 3 or 4 kilometers, north of Yen-chuang, and similar strata underlie most of the lowland, from Po-shan north to the fluviatile plain. Exposures of similar rocks were also noted along the railroad, from Chóu-ts'un to Ts'ing-tau, *i. e.*, at Weï-hién and Ch'ang-ling.

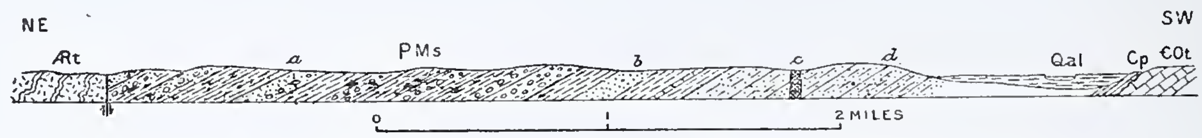


FIG. 14 (Blackwelder).—Sin-t'ai-hién, Shan-tung. Section of Sin-t'ai (Permo-Mesozoic?) series. The contact upon the coal-measures below is concealed by fluviatile deposits. *a* = soft red shales with many layers of coarse conglomerate; *b* = gray shales and thin sandstones; *c* = peridotite dike; *d* = red shaly sandstone.

IN THE SIN-T'AI DISTRICT.

The lowland southeast of Sin-t'ai-hién furnished the only continuous section of the red formation which we were able to examine (Fig. 14). The one unfortunate feature of the occurrence is the concealment of the basal contact with the Po-shan series, by the river Siau-wön-ho and the alluvium of its flood plain. The lowest visible strata are coarse earthy sandstone of brick-red color, characterized throughout by cross-bedding in intricate festoon-like forms. Certain layers are gritty, but the material is not coarse enough to justify the name conglomerate.

After a slight interval, in which the rocks were not observed, the red sandstone is followed by alternating gray silts, shales, and sandstones, in regularly parallel strata. Lenticular bodies of purple mudstone occasionally appear in the gray sandy shales. Where the constituent grains are megascopically identifiable, they are seen to comprise quartz, potash feldspar, mica, cherts of yellow, red, and black colors, a little gray limestone, red hematite, etc. There is a notable lack of such minerals as are commonly derived from volcanic rocks. The composition of the sandstone indicates rather that areas of the T'ai-shan complex were exposed in the drainage district whence the material was derived. We know of no other rocks in North China which could furnish the potash feldspars and mica without sodic feldspars and hornblende. The sandy shales are soft, pure

* See sections and descriptions quoted in Chapter XIII.

gray in color, and contain the only vestiges of fossils found anywhere in the Sin-t'ai series—black bituminous impressions of fragments of unrecognizable plants. This gray member of the series is at least 250 feet thick.

The uppermost portion of the Sin-t'ai series comprises brick-red, or rarely grayish, clays, sandy silts, and conglomerates. Like the rest of the formation in this section they lie inclined 20° to 30° toward the north. If this dip is all due to the subsequent tilting of sediments which had been deposited in a horizontal attitude the clays are not less than 8,000 feet, 2,400 meters, thick. It is possible that some of the inclination was conditioned by deposition of sediments on a sloping surface, but the uniformity of the dip over several square miles, and its coincidence with the dip of the underlying Sinian limestone are evidences which tend in some degree to controvert that hypothesis. The upper red strata themselves are soft massive sandy clays, usually without shaly cleavage, interspersed with sandstones and thin seams of gray and green clays. Ill-defined bands of calcareous nodules, like those occurring in the recent loess deposits, are frequent along the bedding planes. At one place, 4 miles west-northwest of Sin-t'ai, the red clays even contain limestone in isolated strata, ½ to 2 feet in thickness. The rock is creamy white, cryptocrystalline, and breaks in all directions with an irregular or conchoidal fracture. It seems to be barren of fossils and is unlike any other rock seen in the province. The conglomerates occur in thin strata at frequent intervals and at almost all horizons in the red clays. The constituent pebbles, ranging up to 4 inches in diameter, comprise a variety of rocks. The commonest are dark gray limestones of the Sinian system, but there are also pebbles of black quartzite and hornblende-porphyry—the former a rock which was not found *in situ* during our sojourn in Shan-tung. The matrix in which these pebbles are embedded is variable. Frequently it is red and sandy; more often the pebbles are interstratified with the red clays directly, while, in cases, the matrix is calcareous and forms a creamy pink rock, filled with the dark angular pebbles of limestone, etc. Whatever may have overlain the red clays in this section has been cut off by a normal fault of large throw, which traverses the northern side of the valley.

So far as our observations go, evidences of volcanic activity in the Sin-t'ai area are confined to a single dike about 40 feet, 12 meters, wide, which cuts the lower red sandstone about 4 miles south of the city. This is so badly weathered as to be difficult to recognize in the field. It shows spheroidal parting in a soft, decayed, grass-green mass, and in the centers of the spheroids there remain hard nuclei, which prove to be portions of the solid lava. These nuclei were formerly composed of a dark

green peridotite, consisting of olivine with a little magnetite and pyroxene, weathering has long since converted all of the olivine into serpentine. As a result of contact metamorphism, the color of the red sandstones, for a distance of about 1 foot on either side of the dike, has been altered to olive gray; under the microscope we see that the change is due to an alteration in the ferruginous cement of the sandstone.

In the Yen-chuang District.

The principal outcrop of the Sin-t'ai series is a small triangular area east of the Wön-ho, bounded on the south by outcrops of the Po-shan series and on the other sides by normal faults. Scattered exposures occur west of the river also, but there the alluvium covers most of the surface.

The succession already described for the Sin-t'ai district coincides approximately with that here. The red cross-bedded sandstones lie above the coal-measures in an unknown relation, and are in turn overlain by a gray shaly and sandy member and red pebbly clays—all lithologically similar to the rocks of the Sin-t'ai section. The principal peculiarity of the series in this locality is the greater abundance and variety of igneous rocks. They consist of basaltic flows and tuffs, and dikes of at least two kinds of porphyry. The distribution of the basalts is so irregular that in one section which was surveyed across the outcrop they were almost lacking. About 2 miles north of Yen-chuang, however, they are interstratified with the red sandstone, and become so well developed toward the north as to obscure in large measure the gray shales and red clays. This particular mass does not extend far to the east. In numerous dikes there are pale brown mica-feldspar-porphyry, gray hornblende-syenite-porphyry, and a buff-colored porphyry with long acicular crystals of black hornblende. The intrusion of these lavas has had only a very slight effect upon the country-rock, especially where that rock was sandy. The basaltic eruptions occurred contemporaneously with the deposition of both the Po-shan sediments and the lower red beds—a fact which favors the idea that these two series are not widely separated in time. The porphyries are at least partly of later age, for they were observed cutting across both dikes and flows of basalt in each of the two formations.

In the Po-shan District.

From Po-shan northward to Chóu-ts'un, and for some miles both east and west of the branch railroad, the Sin-t'ai formation occupies the surface. In our rapid journey along the main road we could only note that it consisted of red sandy sediments, which include many tuffs and flows and some dikes of greenish lavas, which are probably decayed basalts. Northwest of Chi-ch'uan-hién the red sandstone is conglomeratic in certain

layers, and more frequently contains small pebbles of red jasper, granite, and other hard rocks, sparsely distributed through the strata. The gray sandy shale member appears 2 miles, 3 kilometers, or more south of Chóu-ts'un, but the outcrop is obscured by a mass of basalt, which has the appearance of being an extrusive sheet. This lava is a fresh olivine-basalt in which the pyroxene and feldspars are confined to the ground-mass. Several miles to the southeast there are scattered dikes of augite-syenite-porphyry in which the phenocrysts are large idiomorphic feldspars; olivine is absent.

TERTIARY.

The time following the deposition of the Sin-t'ai series is not represented by any extensive rock formations, except the accumulation of loess, alluvium, and ordinary soils, all of which have been developed in comparatively recent times. We know of only one consolidated terrane younger than the Sin-t'ai series.

WÖN-HO CONGLOMERATE.

The Wön-ho conglomerate is developed locally in central Shan-tung in association with normal faults. The conglomerates were found only on the downthrow side of such dislocations. The hills on the north side of the valley between Ts'ai-kia-chuang and Sin-t'ai-hién are composed partly of these conglomerates and partly of Sinian limestones. South of Sin-t'ai there are isolated exposures of the same formation, and von Richthofen reports, from the region southeast of Sin-t'ai, rocks which appear to be identical. North and east of Yen-chuang there are other conglomerates of this character.

The Wön-ho formation is composed of massive beds of coarse gravel, which is partially cemented into a rather firm conglomerate. So far as observed, the formation does not contain any interbedded layers of other rocks, but consists of conglomerate from bottom to top, through a thickness of at least more than 100 feet, 30 meters, in some localities. The pebbles are often angular, but are usually rounded as if water-worn to a greater or less degree. They are composed very largely of dark Sinian limestones and pieces of chert, which may have been included in the limestone. In the exposure south of Sin-t'ai-hién there are associated with the limestones a variety of other rocks; gray and black quartzites, green porphyries, pink granite, coarse white sandstone, basalt, vein-quartz, and soft red sandstone.

The relation of this formation to the older systems was not definitely determined, as basal contacts were not actually observed. A few miles

east of Ts'ai-kia-chuang the conglomerate lies upon Sinian limestones; 5 miles south of Sin-t'ai-hién it lies upon the basal red sandstone of the Sin-t'ai series; and east of Sin-t'ai it appears to overlie the red gravelly clays in the upper part of that formation. The fact that it rests promiscuously upon several different formations is in itself a strong indication that it is unconformable on the older strata. Further evidence on this point is furnished by the structure of the rocks bordering the fault line east of Sin-t'ai; the red gravelly shales here dip 22° toward the fault, but the conglomerate scarcely half a mile away lies nearly horizontal (Fig. 15). Lastly, we have the fact that the conglomerate beds south of Sin-t'ai contain fragments of soft red sandstone. Although the Man-t'o shales do locally contain a thin bed of red sandstone, yet the only large

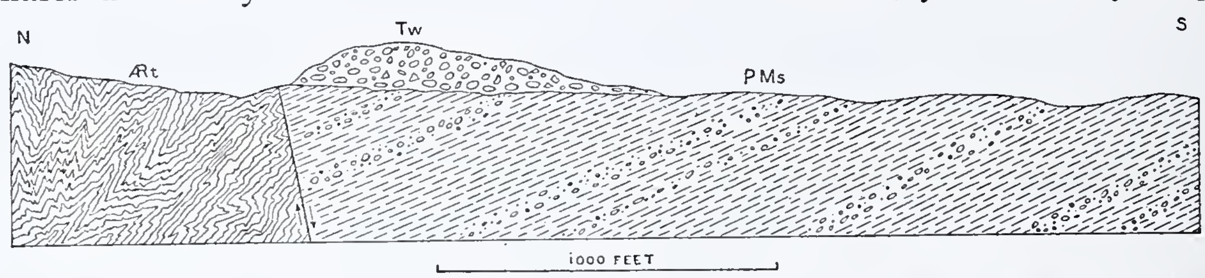
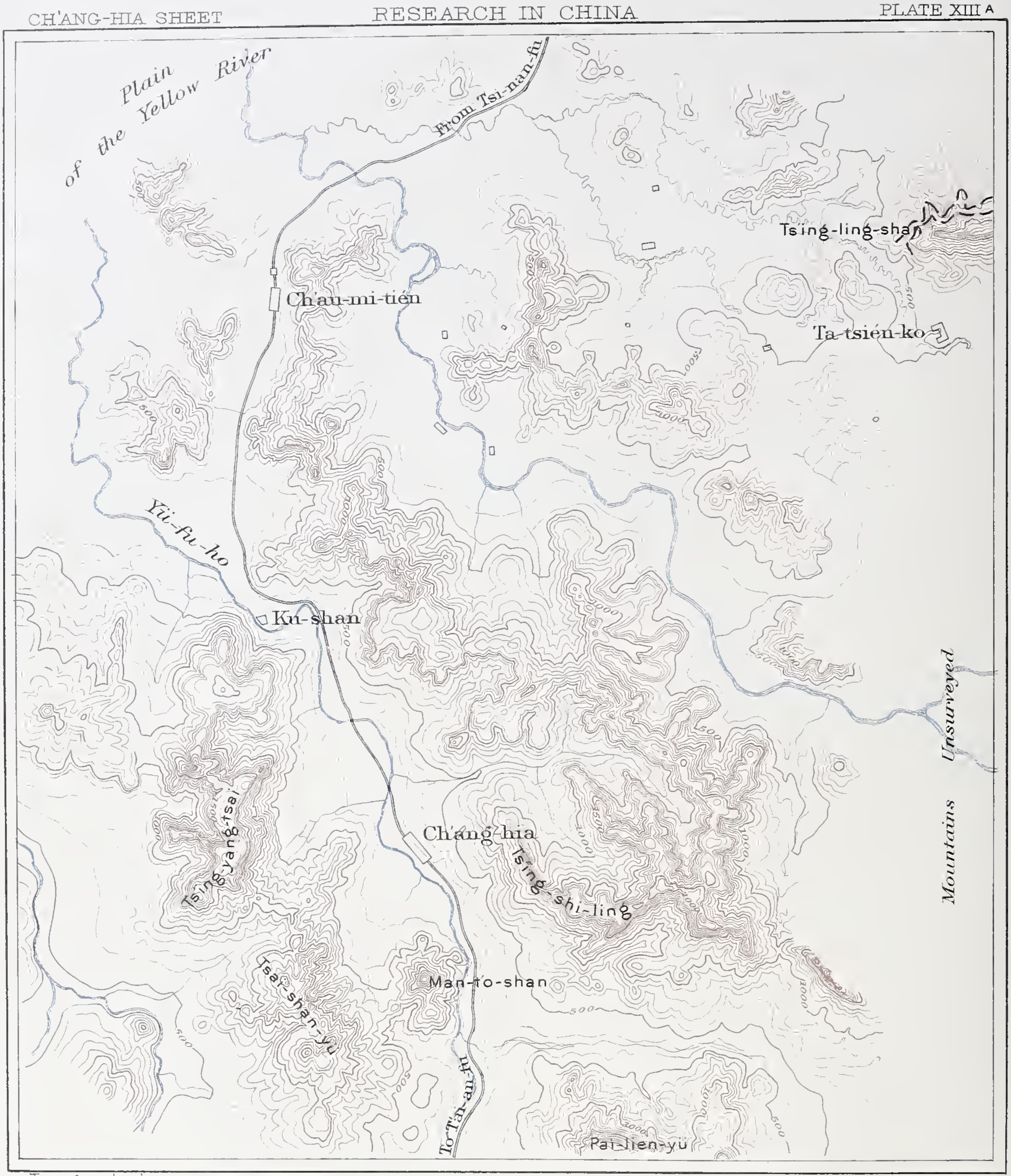


FIG. 15 (Blackwelder).—Sin-t'ai-hién, Shan-tung. Wön-ho conglomerate (Tertiary?) lying upon eroded surface of Permo-Mesozoic (PMs) red shale adjacent to ancient normal fault.

body of such rocks which we found in Shan-tung is the basal member of the Sin-t'ai series. If the fragments contained in the conglomerate were derived from that formation, it is to be inferred that the red strata were undergoing erosion at that time, and that the conglomerates are therefore unconformable upon the Sin-t'ai series.

The Wön-ho conglomerates are evidently connected with the period of normal faulting. The formation has the character of a deposit spread out along the bases of recent fault-scarps by the streams which were engaged in reducing the elevations formed by the faults. From physiographic evidence, Willis infers that the faulting occurred during the early Tertiary. We therefore assign the conglomerates tentatively to that age.



Topography by Bailey Willis.

A. HOEN & CO. BALTIMORE.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

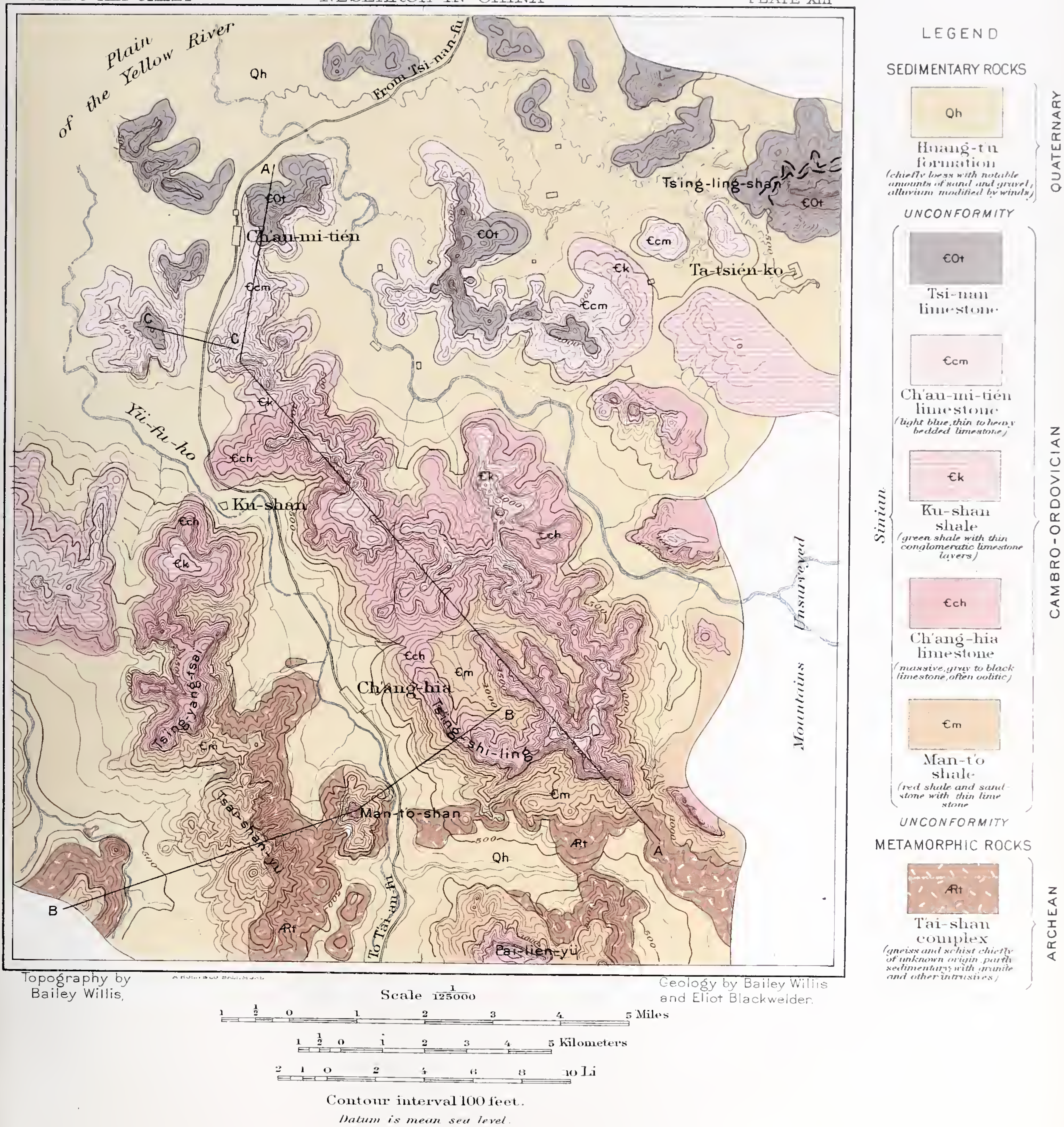
1 ½ 0 1 2 3 4 5 Kilometers

2 1 0 2 4 6 8 10 Li

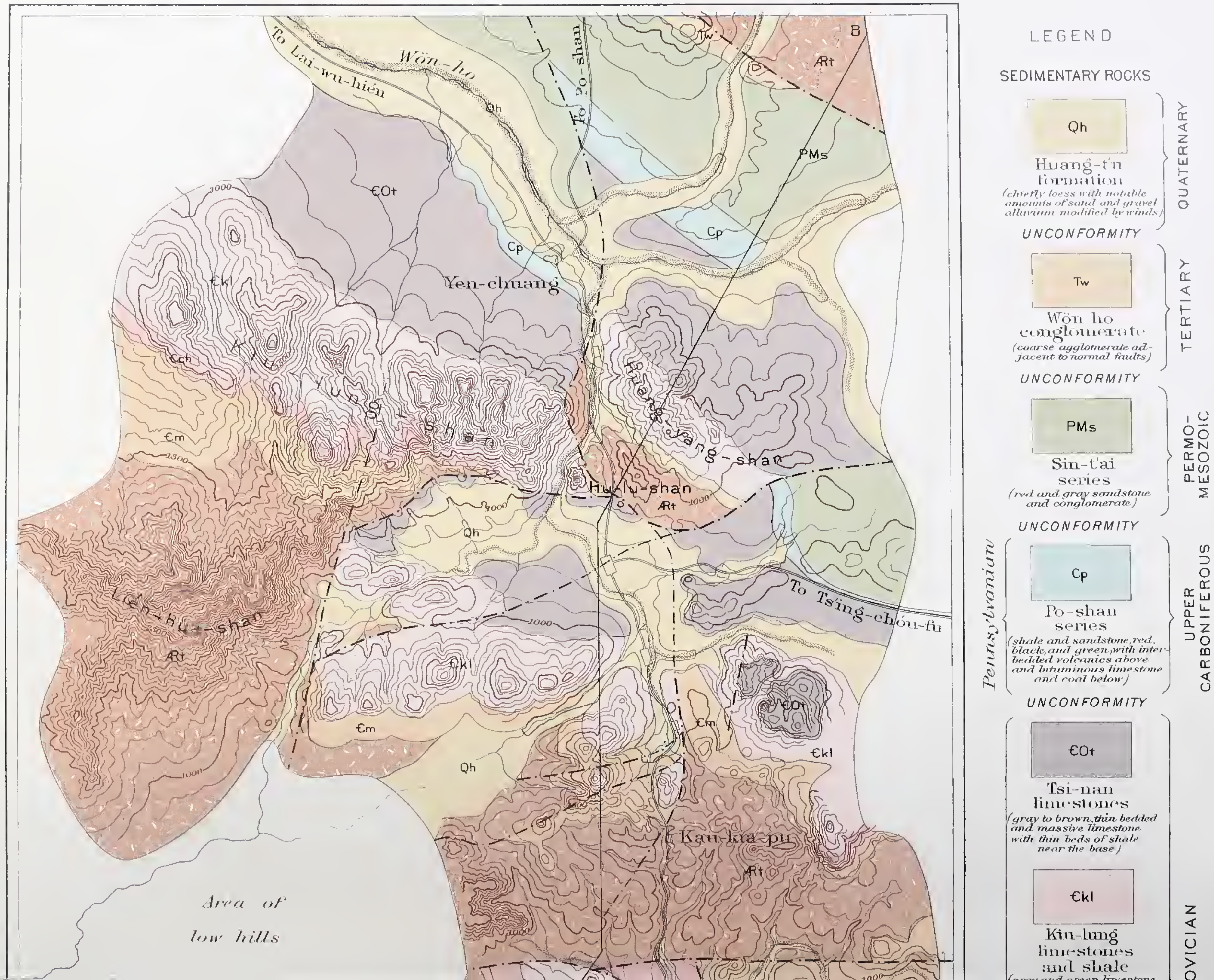
Contour interval 100 feet.

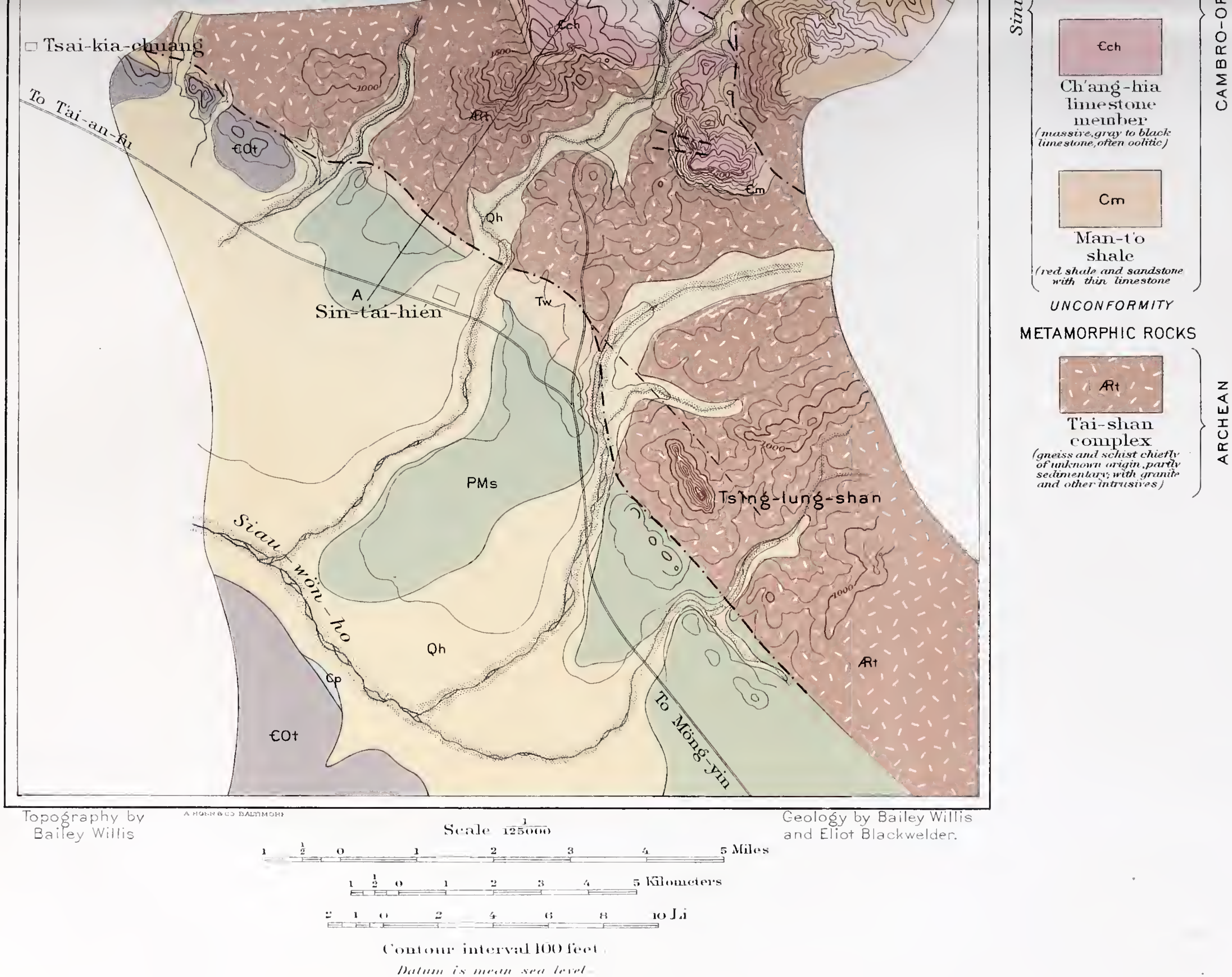
Datum is mean sea level.

Topographic Map of the Ch'ang-hia District
Province of Shan-tung



Geological Map of the Ch'ang-hia District
Province of Shan-tung


To Lai-wu-hién
Wön-ho
To Po-shan
Yen-chuang
Kiu-lung-shan
Huang-yang-shan
Hu-lu-shan
Lén-hua-shan
To Ts'ing-chóu-fu
Kau-kia-pu
Area of low hills
B
€Ot
Cp
PMs
Tw
Qh
Ʀt
€kl
€ch
€m
1000
1500
2000
LEGEND
SEDIMENTARY ROCKS
Qh
Huang-t'u formation
(chiefly loess with notable amounts of sand and gravel alluvium modified by winds)
QUATERNARY
UNCONFORMITY
Tw
Wön-ho conglomerate
(coarse agglomerate adjacent to normal faults)
TERTIARY
UNCONFORMITY
PMs
Sin-t'ai series
(red and gray sandstone and conglomerate)
PERMO-MESOZOIC
UNCONFORMITY
Cp
Po-shan series
(shale and sandstone, red, black, and green, with interbedded volcanics above and bituminous limestone and coal below)
Pennsylvanian
UPPER CARBONIFEROUS
UNCONFORMITY
€Ot
Tsi-nan limestones
(gray to brown, thin bedded and massive limestone with thin beds of shale near the base)
€kl
Kiu-lung limestones and shale
OVICIAN



Geological Map of the Sin t'ai District Province of Shan-tung

CHAPTER III.

STRUCTURAL GEOLOGY OF SHAN-TUNG.

By Bailey Willis.

GENERAL OBSERVATIONS.

Method of discussion.—In the preceding chapter on the stratigraphy of Shan-tung several great systems of rocks are distinguished according to their petrological and stratigraphical characteristics. They are equally distinct in individual structural phenomena, and yet they have also all suffered deformation in common. In discussing the structure we shall follow the order of development by beginning with the oldest and describing those structures which are characteristic of each successive system; and then, in appropriate historical sequence, we may give an account of the structures common to all. We shall thus review: (1) the Pre-Cambrian, (2) the late Paleozoic or early Mesozoic, and (3) the late Mesozoic or Tertiary epochs of deformation.

The mountain peninsula of Shan-tung is a land which was deeply eroded in Pre-Cambrian time, and sank beneath the Cambrian sea; which was buried under Pre-Silurian sediments to a depth of probably 5,000 feet, 1,500 meters; which was raised without deformation, slightly eroded, and further buried under late Carboniferous and Mesozoic sediments and local masses of extrusive igneous rocks; which after the close of the Paleozoic suffered slight folding by compression; which later was broken by normal faults into relatively small blocks that experienced great dislocation; and which has since been deeply eroded. During the latest geologic epochs extensive superficial deposits have accumulated in valleys and on plains. Considered as a whole, Shan-tung is, therefore, an irregular mosaic; wide areas of the oldest rocks are inlaid with fragments of Paleozoic and Mesozoic strata, and much of the surface is covered by the dust of later ages.

The following description is based upon our detailed studies of two typical districts, and reconnaissance notes of our journey from Tsi-nan-fu to Po-shan.

STRUCTURE OF THE T'AI-SHAN COMPLEX.

Metamorphism and folding.—The T'ai-shan complex is composed of metamorphic rocks, which are, to a great extent, schistose and recrystallized. The metamorphism of all the older members is extreme; only the relatively young granite is but slightly altered. These changes of the

original igneous or sedimentary rocks appear to have developed in that deep zone where great pressure is the dominant factor affecting molecular and mass alterations. The resulting petrographic characteristics and the relations of the several members are described in the section of the preceding chapter, relating to the rocks of the T'ai-shan complex. The larger structures, in so far as they are those of folded rocks, may be isoclinal and involved with complex overthrusting; but they are intricate, as are the structures of the Laurentian.

Observations on the local strike and dip of schistosity may be noted as follows:

Ch'ang-hia district: 1 mile, 1.6 kilometers, northwest of Ch'ang-hia; gneiss; strike N. 10° W., dip 20° W.

Mount T'ai-shan in the ravine below Heaven's South Gate; gneiss and schist; strike N. 24° W., dip vertical.

Sin-t'ai district; north of Ts'in-lung-shan; N. 40° W., dip 70–80° SW.

Jointing.—The structures developed in rocks of the T'ai-shan complex under conditions of anamorphism are common to every part of the mass. As pointed out by Van Hise,* this is frequently characteristic of deformation in a deep-seated zone, and stands in strong contrast to disruptive structures developed under conditions of katamorphism. In the latter, rupture is confined to planes, which circumscribe blocks that remain unbroken. The T'ai-shan complex has suffered this latter class of deformation also, the rocks being extensively jointed and thus divided into larger and smaller blocks. In general, the jointing is at close intervals, but occasionally there are masses in which the blocks between joints may measure as much as 100 feet, 30 meters. An interesting example occurs east of Sin-t'ai, where the striking peak, the Ts'in-lung-shan, rises 600 feet, 120 meters, above the valley floor; the mass of the pinnacle is composed of huge blocks, between widely spaced joint-planes, whereas rocks of the surrounding valley are minutely jointed.

It is evident that the schistosity developed in the deep zone of anamorphism is older than the jointing in the zone of katamorphism. The former is certainly long Pre-Cambrian; the latter may have resulted during the elevation and denudation of the land mass in later Pre-Cambrian time, and this is probably the case; it may also have been produced with the jointing in the overlying Sinian strata, or it may have been effective in determining the location and direction of joints in these strata. A closer study than that which we were able to make of the relations and directions of joints in the two rock systems, where they come into contact, is necessary to discussion.

* A Treatise on Metamorphism, Van Hise; U. S. G. S. Monograph XLVII, page 673.

STRUCTURE OF THE SINIAN SYSTEM.

GENERAL CONSIDERATIONS.

Original lay of the strata.—At the base of the Sinian system is a plane of unconformity, which is extensively exposed in the Ch'ang-hia and Sin-t'ai districts, and is a flat, even surface. The slight irregularities of the basement, which project up into the lowest Sinian sediments, are insignificant as compared with the thickness of superincumbent strata; and it is only when considered over extensive areas that the surface departs notably from a flat. In so far as it does so, it conforms to the folds in the Sinian system, and the flexures are clearly effects of deformation and not original. It is therefore a reasonable inference that the surface upon which the Sinian strata were first laid down was one which had been reduced by erosion and marine planation to a condition of flatness and evenness. The lowest beds of the Sinian system are shales and sandstones, in general about 500 feet, 150 meters, thick. They filled in the slight inequalities in the surface of the Pre-Cambrian rocks, and when the conditions of sedimentation became favorable to the deposition of limestone, these clastic sediments had the nearly flat surface of a gently sloping sea-bottom. Measurements of the limestone strata are in general uniform; only in the Ch'ang-hia oolite do we find considerable variations, and there the differences in thickness of the limestone masses appear to be compensated by accumulations of shale. The overlying Ch'au-mi-tién limestone is very uniform in character and thickness, and the same is true of the great Tsi-nan-fu limestone, so far as it is preserved. If these observations be correct, the Sinian system, within the province of Shan-tung, originally presented an extensive and essentially flat mass of strata; initial dips were very local and slight, and there were no long lines of initial flexure, which, in later deformation, might have given rise to prominent and extensive anticlines and synclines. We would therefore expect that deformation of the Sinian system by compression would result in local folds within the system, and that where larger flexures had developed they would be of a very broad and gentle character. This inference accords with the observed facts.

Relative rigidities of the Sinian formation.—The Sinian system, considered as a whole, is a rigid mass, capable of transmitting thrust throughout a large area; but the individual formations differ greatly in rigidity.

The Man-t'o formation, at the base of the system, is composed of 500 feet, 150 meters, of thinly interbedded shale and limestone, with occasional thin beds of sandstone. The layers are discontinuous, except the limestones, which, though persistent, are too thin to affect the com-

petency of the mass. Planes of parting are very numerous, and the formation is capable of much internal movement. It was consequently weak in opposition to a tangential compressive stress, and liable to local flexure.

The Kiu-lung formation overlies the Man-t'o formation. In some localities it includes an extremely massive limestone, the Ch'ang-hia oolite, 500 feet, 150 meters, thick, but elsewhere it is represented by thinly bedded shales, in which occur discontinuous limestone lenses. Where the massive oolite occurs, the formation is rigid and capable of transmitting thrust throughout that area; but where it is composed of shale the formation is locally weak and flexible. These two mechanical elements occur in one horizon, and consequently afford an opportunity for the development of irregular structures through general tangential pressure.

The Ch'au-mi-tién and Tsi-nan limestones constitute a structural unit. Essentially similar in constitution and in bedding throughout, they form a thickness of 3,000 feet, 900 meters, or more of massive strata, with relatively few and closely adherent bedding planes. A sequence of calcareous strata of this thickness and character belongs among the most rigid components of sedimentary systems. It is capable of transmitting thrusts throughout a very wide area, and to it the rigidity of the Sinian system is due. Where the lower member of the Tsi-nan limestone was locally shaly, it served to distribute motion between the rigid limestones above and below.

Distribution of structures.—If we regard the Sinian system, together with a part of the underlying T'ai-shan complex, as a mechanical strut subject to horizontal compression, we may distinguish three elements or parts, namely: the T'ai-shan complex, which, by its vertical structure, is sharply distinguished from the horizontally bedded Sinian; the rigid limestone mass of the upper Sinian; and between these two, the relatively flexible layer of the Man-t'o and Kiu-lung formations. Such a strut presents two stiff elements and a weak intermediate one. When compressed it may, if the resistance to horizontal movement of the lowest and uppermost elements be the same, yield by bending in a large curve, and the necessary adjustment on the longer and shorter sides of the curve will take place chiefly by motion in the inner member. Or, in case the resistances to horizontal motion of the lowest and uppermost members be unequal, these two members will move past one another, the intermediate one serving as a plane of motion and being folded and dislocated accordingly.

It follows from these considerations that we may expect to find local folds and overthrusts in the Man-t'o and Ch'ang-hia formations, which may not be shared, at least to the same extent, by the T'ai-shan complex or the great limestones of the upper Sinian.

STRUCTURE OF THE SINIAN IN THE CH'ANG-HIA DISTRICT.

Detailed observations.—In the Ch'ang-hia district strata of the Sinian system dip gently toward the northwest, so that, within the area surveyed in detail, in a distance of 16 miles, the entire sequence passes underneath the plain. This fact was correctly described by von Richthofen,* who reviewed the strata rapidly, in journeying along the highway, which here leads in a northwesterly direction. It happens that the valley, and consequently the highway, lies near the axis of a broad anticline, the pitch of which is represented by this northwesterly inclination. The dips on the flanks of this anticline are not noticeable in a general view, and escaped the attention of von Richthofen.

The following are some of the more notable local structures: Section AA, Plate XV, shows the attitude of the strata in the ridge east of Ch'ang-hia, from the base of the Man-t'o northwestward and northward to the point where the Ts'i-nan limestone disappears under the plain. The gentle undulatory northwest pitch of the massive Ch'ang-hia oolite, the Ch'au-mi-tién limestone, and a small part of the Tsi-nan is clearly brought out.

On the line of this section a local feature of deformation in the Man-t'o shale and the lowest layers of the Ch'ang-hia oolite is well exposed in a valley northeast of Ch'ang-hia. In the thin-bedded Man-t'o shales there occurs a sharp anticline which is overturned toward the south. The strike of the axis is about N. 75° E. The nearly vertical and overturned dips occur also in the lower of the limestone layers, but are not represented in the upper portion of the Ch'ang-hia oolite, which is practically flat.

A section on a line at right angles to the preceding is shown in BB. It passes through the isolated hill, Man-t'o Butte, and exhibits a difference of elevation between the base of the Man-t'o formation on the east and west of the valley, of 700 feet, 210 meters. Von Richthofen observed this difference and commented upon it.† Believing the strata to be horizontal, he inferred the existence here of a normal fault, of a type which is common elsewhere in the province. The base of the formation dips in Man-t'o Butte, as shown in the section, and its continuation westward may readily have risen higher than we now observe, to connect in a fold with the outcrop in the next ridge. The axis of the fold has been eroded. We did not observe any evidence of faulting.

In the northwestern part of the area mapped, in the valley south of Ch'au-mi-tién, the limestone of that name shows dips of 60° to 80°, while striking nearly north and south. The probable structure is delineated in Section CC, Plate XV, as a sharp syncline. Occurring in the base of the Ch'au-mi-tién limestone, and thus involving a part of the rigid uppermost

* China, vol. II, pp. 195–197. † Ibid., p. 196.

member of the Sinian system, this fold probably indicates an even larger one in the underlying formations. There are evidences of similar folding in the adjacent hill, a mile to the northwest; but the structures are isolated by the surrounding alluvium, and their extension can not be made out.

In the northwestern part of the Ch'ang-hia district is a conspicuous mountain, the Ts'in-lung-shan, which is composed of the lower part of the Tsi-nan limestone, together with a lower member which is here of a shaly character and has served the rigid limestone as a surface of relatively easy dislocation. The western end of the mountain exhibits two over-thrust faults involving these formations (see Plate XV). The dip of the faults is gentle and toward the northwest. They may be interpreted as evidences of unequal resistance and of local yielding by dislocation to a thrust, which, in the underlying strata probably produced a fold.

Outside the Ch'ang-hia district, between it and Tsi-nan-fu, and 7 miles, 11 kilometers, southwest of that city, the Tsi-nan limestone forms a ridge running north and south. The strata are folded in a broad syncline, south of which occur several smaller folds of a peculiar rectangular form. The dip changes abruptly from horizontality to verticality, producing a step-like effect.

STRUCTURE OF THE SINIAN IN THE SIN-T'AI DISTRICT.

Absence of folds.—The masses of strata of the Sinian system remaining in the Sin-t'ai district are comparatively small and are isolated. They have a general dip of 15° to 20° toward the north, sometimes a little to the east, sometimes to the west, of that point. In the northern part of the district the Sinian system is succeeded by the coal-bearing Po-shan formation of Upper Carboniferous age, and the strata are, so far as local observations can determine, conformable as to dip. In the upper part of the Po-shan formation occur tuffs and lavas, which are also in conformity with the earlier rocks. Hence we may infer that whatever compression the strata in this part of Shan-tung suffered toward the close of the Paleozoic or in the early Mesozoic was without effect in folding the rigid mass of the Sinian system and overlying rocks.

NORMAL FAULTING.

IN THE SIN-T'AI DISTRICT.

In general.—Normal faulting is strikingly developed in the western mountain district of Shan-tung. Von Richthofen recognized it in his first reconnaissance, 1869, and incorporated his interpretation in a map.* Our own observations confirm his, and supplement them with some details. Before stating the general relations, I give the facts of faulting as we mapped them in the Sin-t'ai district.

* Ein Versuch einer tektonischen Karte des nördlichen China.

In the Sin-t'ai district normal faults are developed in a complex manner, and it is probable that the structures there observed are characteristic of the Wön-ho watershed. So far as they have been accurately observed in detail, these faults do not follow any definite system in their horizontal arrangement. They run indifferently toward any point of the compass; they join or intersect and are frequently crooked. Nevertheless, in the Sin-t'ai district they possess a definite habit of dislocation; all faults which run nearly north and south have the upthrow on the eastern side, except in one instance; and for all faults which run nearly east and west the upthrow is, without exception, on the northern side. By reference to section DD, Plate XV, the effect of this relation of upthrow to downthrow may be seen to compensate for the dip of the Sinian strata, so that in going from south to north we repeatedly meet the same formations, although the constant northern dip should bring younger strata down to the level of observation. This happens only in the coal-basin of Yen-chuang, where coal-measures and the overlying volcanic rock cover an extensive area. Immediately north of them, however, the Pre-Cambrian gneiss forms the surface of the Wön-ho valley, and extends northward to Meï-yü-shan.

Details of faulting.—The table on page 67 gives certain details concerning the nine principal faults observed in the Sin-t'ai district. The faults are designated by letters, which will be found appropriately placed upon Plate XIV. A comparison of columns 2 and 3 permits a study of the relations of the direction of faulting to upthrow and downthrow sides. Columns 4 and 5 give the dimensions of the faults in terms of length and displacement; the length is necessarily somewhat indefinite, as it is rarely the case that the end of a fault can be even approximately determined. The existence of the fault is recognized where diverse formations are brought into contact; where the displacement is within one formation, and particularly where it runs into gneiss, its amount can not be determined. Inasmuch, however, as strata of the Sinian system are depressed below the present surface of erosion somewhere along each one of these major faults, it seems probable that the displacement is less where this is not the fact than where it is; accordingly, faults running into the gneiss are thought to have less displacement in that direction and probably to disappear.

A fault which is distinguished by great length and displacement beyond the others is Na. It has a northwest-southeast course and is followed by the valleys of the Tung-wön-ho and the Siau-wön-ho. Its length, as mapped by von Richthofen, is about 75 miles, 120 kilometers; its throw, as determined at the coal-mines, 7 miles, 11 kilometers, northwest of Sin-t'ai, amounts to the full thickness of the Sinian system in this

region, 4,200 feet, 1,260 meters, plus something more than 100 feet, 30 meters, of coal-measures, plus several thousand feet of gneiss. The latter element is estimated by extending the Sinian strata, which occur northeast of Sin-t'ai, upon the there observed dip, until they intersect the fault-plane. This estimate gives a probable minimum displacement of 8,000 feet, 2,400 meters. Near Sin-t'ai the displacement may be greater. The base of the Sinian system on the upthrow side would lie at the same altitude above the surface of the plain on the downthrow; this surface consists of the sandstones and shales of the Sin-t'ai series, whose thickness is indeterminate, but probably several thousand feet. Beneath these presumably lie the strata of the Sinian; if we admit a maximum thickness of the Sin-t'ai series as 12,000 feet, 3,600 meters, the displacement of the fault would not be less than 20,000 feet, 6,000 meters, but this is probably a very excessive estimate.

A series of faults of great magnitude begins with Nh. Only a small section of the southern one appears in the special map of the Sin-t'ai district; but we followed the series northward, past Meï-yü-shan, and found it included one described by von Richthofen.* The length of the series is something more than 100 miles, 160 kilometers, in a general north-south direction. As its southern end it joins with the fault Ng, which may be considered its continuation, and, bending eastward, extends beyond the area of our observation (see Plate XII). The displacement of the fault Nh, where we have definite data for determining it, north of Yen-chuang, is about 4,000 feet, 1,200 meters, and does not appear anywhere to be more than half the displacement of the fault Na. It would, perhaps, be greater were it not for the fault Ni, which is an eastern branch of Nh and which has even larger displacement. Along Ni, gneiss on the upthrow side is in contact with igneous rocks which overlie the coal-measures to an unknown thickness. We thus have for this displacement the full thickness of the Sinian series and the Po-shan formation, probably 5,000 feet, 1,500 meters, plus an unknown amount of igneous rocks, plus an indeterminate thickness of gneiss; a throw of 8,000 to 10,000 feet, 2,400 to 3,000 meters, seems a moderate estimate.

Of the short faults which lie within the area of accurate survey, Nc is noteworthy for the very great variation in throw in a short distance. Near its eastern end the fault lies wholly in the Man-t'o formation, and the displacement can not exceed 200 or 300 feet, 60 or 90 meters; a short distance further east the break ceases altogether. Four miles, 6 kilometers, further west the Kiu-lung formation is thrown down in contact with gneiss, and we may estimate the displacement by measuring from the base of the Sinian in the downthrow to the same horizon in the upthrow, extended

* China, vol. II, p. 238.

TABULATION OF DETAILS RELATING TO NORMAL FAULTING IN THE SIN-T'AI DISTRICT.

Designation.	Course.	Upthrow is on the	Length in miles.	Length in kilometers.	Displacement in feet.	Displacement in meters.	Remarks.
Na	NW.-SE. varying to N. 10 W.	NE. side	75 or more	120 or more	8,000 to 20,000?	2,400 to 6,000?	The great fault followed by the Tung-wön-ho and Siau-wön-ho valleys.
Nb	N.-S. to NW.-SE.	E. side	3+	5+	0 to 500	0 to 150	Approaching Nc, Nb branches and is apparently cut off by Nc. Is followed by a small brook in a ravine in the upthrow.
Nc	E.-W.	N. side	6+	9+	0 to 6,800±	0 to 1,075±	Nc and the branch of Nb are crossed by a tributary of the Siau-wön-ho, flowing south from the upthrow to the downthrow.
Nd Nd1 Nd2	N.-S. branching SW. into three parts	E. side and N. side	3±	5+	0 to 500	0 to 150	Nd, Nd1, and Nd2 form a bunch of small faults branching at acute angles. They extend across the divide between the Wön-ho and Siau-wön-ho, which is established on gneiss and Sinian strata, indifferently.
Ne	N. 75 E.	N. side	3	5	0 to 1,000	0 to 300	Ne is followed by a col and two brooks, adjusted to soft shales.
Nf	N. 15 E.	W. side (exceptional)	5	8	0 to 2,200	0 to 670	Nf is the eastern boundary of the granite mass of the Lién-hua-shan, which represents the upthrown block.
Ng	N. 80 E.	N. side	8+	13+	1,000 to 4,000	300 to 1,200	The Kiu-lung range is on the upthrow and is crossed by the tributary of the Wön-ho, flowing north from the downthrow to the upthrow on the line of the fault Nh.
Nh	N. 10 W. to S. 10 W. trending SE. and E. into Ng	E. side	10+	16+	4,000+ to 10,000?	1,200+ to 3,000?	Nh is one of a series of faults of central western Shan-tung. It extends from Yen-chuang N. by W. The series extends past Meï-yu-shan and Po-shan, across the Wön-ho valley; it is crossed by branches of the Wön-ho from upthrow to downthrow.
Ni	N. 70 W.	N. side	10+	16+	10,000±	3,000±	Ni lies in the northeast corner of the Sin-t'ai district, and only a small section of it was seen. It appears to be a branch of Nh, and thus to be one of the more important faults of the province.

from the outcrop of the Man-t'o formation, which occurs 2 miles, 3 kilometers, further north; the result is 6,800 feet, 2,000 meters. Two miles, 3 kilometers, further west this fault runs into the gneiss and its displacement becomes indeterminate, but probably diminishes westward as it does eastward.

The fault Nf is peculiar in that the upthrow side is on the west, whereas in all approximately parallel faults it is on the east. The effect is to place the valley south of the Kiu-lung range in a graben, and to raise the conspicuous granite mass of the Lién-hua-shan to a greater altitude than any other mountain of the vicinity.

If one should attempt to discover systems among the faults of the Sin-t'ai district, and to this end should arrange the faults in groups according to their courses, there might perhaps be distinguished two or three; namely, north-south, east-west, and northwest-southeast systems. There are, at least, representatives which have these directions. If one further sought to determine the relative ages of the systems, one might discover that the north-south faults, having the upthrow on the east, terminate in the east-west faults, and that the latter are themselves cut off by Nf, having the upthrow on the west. A special study of this question, in the hill Hu-lu-shan, which lies in the triangle between Ng, Nh, and a branch fault connecting them, showed the following: a fault striking N. 25° W. and dipping 85° E. is cut off by one striking N. 30° E. and dipping 65° NW.; and the latter is terminated by a third which strikes N. 80° W. and dips 60° to 80° S. The relations appear to correspond with those of the faults Ng and Nh, to which these small faults are parallel. Yet, although the observations, in general and in detail, indicate that the faults do terminate one against another, it does not follow that they are of different ages. Nh is clearly traced into Ng, and may quite as well be considered continuous with it as terminated by it. Nd1 and Nd2 appear to be branches trending southwest from a north-south fracture. Nb may be regarded as a branch of Nc, and Na is continuous, though changing its course from northwest to north and again to northwest. It seems more reasonable to regard these faults as effects of a strain set up simultaneously throughout the whole mass, which resulted in irregular fractures, according to variable local conditions.

The details of faulting, which have been described in the preceding paragraphs, lie within a more extended area in which normal faulting is the principal structural phenomenon (see map, Plate XII). We do not know how much of that area is cut up as intricately and closely as is the Sin-t'ai district, but the faults which we traced extend beyond it, and the mountains within our range of vision exhibited similar disconnected features.

NORMAL FAULTING IN WESTERN SHAN-TUNG.

Distribution.—As mapped by von Richthofen three principal faults define the broken area and a fourth cuts into it north and south. Of the three which bound it, one lies along the southern base of the T'ai-shan chain, striking N. 65° E., with the upthrow on the northern side. The existence of this fault is indicated by the presence of rocks of Middle Cambrian age in the plain near T'ai-an-fu, at the base of the great mass of granite and gneiss of Pre-Cambrian age, which constitutes the T'ai-shan. This may be called the T'ai-shan fault. The second limiting fault lies along the southwestern margin of the area, between the Sinian rocks of the southwestern foothills and the Pre-Cambrian rocks of the Kiu-nü-shan and Shï-mön-shan. We did not observe this fault and it has not been traced by a geologist throughout its extent. It was observed by von Richthofen near I-chóu-fu, and is represented on our map as given by him. It is possible that it is not a continuous fault, but is offset, as are the two ranges above named (see Plate XII). The upthrow is on the northeast, and the fault is closely parallel and similar in dislocation to that which we have designated Na and which passes through Sin-t'ai. On the northeastern side of the faulted area von Richthofen shows a line of contact between the Sinian and the Pre-Cambrian rocks of the I-shan, which appears to indicate another great dislocation nearly parallel to these two. The fault which comes into the area from the north was recognized by von Richthofen near Po-shan, and is one of the series traced by us to Yen-chuang.

The effect of these great dislocations is to define a sunken area within high mountain chains. Roughly speaking, the area is a triangle. Its acute apex is pointed toward the west and is situated west of T'ai-an-fu, between the T'ai-shan and the Shï-mön-shan. Its southwestern side corresponds with the Shï-mön-shan fault. Its northern side, consisting of the T'ai-shan and the I-shan faults, is offset along the north-south Po-shan fault, and its southwestern side sinks gently beneath the adjacent sea without a break. As the upthrow of all these principal faults is on the northeastern or northwestern side, the general effect is to produce a series of tilted blocks.

Within the area of dislocation the details of faulting are such that there are many peaks quite as high as the crests of the surrounding ranges, except the T'ai-shan. As will be further discussed in connection with the physiography, the master streams lie along the downthrown margins of the greater blocks, and the valley of the Wön-ho, which, even for Shan-tung, is unusually broad and level, probably corresponds with an extensive depressed area.

Rate of displacement.—It is not supposed that these normal faults, having displacements of 500 to 10,000 feet, 150 to 3,000 meters, developed suddenly; neither is it thought that the movement was so gradual as to produce no inequalities of the surface. The latter could only be true if the rate of general denudation were the same as that of dislocation. We shall see in discussing the structural facts of Shan-si and Shen-si (Chapter IX), that there are in that part of China normal faults, which have so developed as to produce mountain walls 4,000 to 5,000 feet, 1,200 to 1,500 meters, high; we are inclined to think that the dislocations in Shan-tung resulted in similar topographic effects, or in other words, that the rate of dislocation was notably more rapid than that of general denudation.

There is another process with which the rate of displacement may be compared, namely, that of corrasion. Did displacement on these normal faults proceed more rapidly than the deepening of channels by the major streams of the region? If so, we should find the rivers flowing from the upthrown blocks to the downthrown blocks; that is, in a consequent relation to the structure. If we examine the maps with reference to this point, we see that in most cases the rivers of the Sin-t'ai district do flow from the upthrow to the downthrow, and may, accordingly, be regarded as consequent streams, determined in their courses by the effects of faulting. There are two cases to the contrary, both of them in relation to the fault Ng. Two tributaries of the Wön-ho, flowing north, cross this fault from the downthrow to the upthrow, apparently as antecedent streams. Both of them are, however, peculiarly situated. The one further west, which joins the Wön-ho near Yen-chuang, follows the fracture zone of the fault Nh. Its course may readily be explained as one adjusted to an easily corraded zone of fractured rock, especially as the effect of faulting is to introduce a belt of soft gneiss and schist between the relatively hard limestone masses of the Kiu-lung-shan and the Huang-yang-shan. In the long cycle of erosion which has elapsed since the faulting occurred, the development of a valley in this position by retrogressive erosion and piracy could hardly fail to take place. The eastern one of the two tributaries may also be considered as having been developed in the natural growth of the Wön-ho river, the master stream of the region, which here lies so near at hand that it would be a remarkable fact if it had not drawn to itself the drainage of this district.

We conclude, therefore, that the evidence to be found in the somewhat limited Sin-t'ai district indicates a consequent relation of the streams to the relief produced by normal faulting; and this inference is sustained on broader grounds when we consider the relation of the great valleys of the Wön-ho, Siau-wön-ho, and Tung-wön-ho to the major normal faults.

In its bearing upon the question of rate of displacement, this conclusion indicates that the relief due to faulting developed more rapidly than channels were deepened by master streams at the time of faulting. It will appear in considering the course of the Huang-ho, and discussing the physiography of Central China, that the same is now true even of that great but overloaded river.

Date of faulting.—The youngest rocks which are traversed by these normal faults, and whose age has been definitely ascertained through fossils, are of the upper Carboniferous. Succeeding them, and also cut by the faults, are volcanic rocks, which are tentatively assigned to the Permian by von Richthofen. We have no new evidence to offer as to the Permian or Triassic age of these eruptives, but agree that they are probably not younger than early or middle Mesozoic. We may, therefore, say that the normal faults are certainly Post-Carboniferous and in all probability Post-Triassic. This is as far as the evidence of stratigraphy enables us to go in determining their age; but physiographic facts afford narrower limits.

As is more fully set forth in the discussion of the physiography, the relief of Shan-tung presents aspects of a more than mature character; thus while the faulted structure invites comparison with the Basin Ranges of the United States, the topographic aspects do not in the same degree, since in Shan-tung we find isolated mountain groups, whereas in the Great Basin we see continuous mountain ridges. In the Sin-t'ai district the isolation of mountain groups is due to the faulting itself, but in the T'ai-shan, the Shï-mön-shan, and Kiu-nü-shan the isolated mountains constitute a chain, having the linear though interrupted character of a dissected ridge. Such these mountains are. They were formerly continuous ridges, but they have been cut through by consequent streams developed on their scarps and back slopes. A similar process of dissection is begun in the Basin Ranges, but it is very far from being equally advanced. Discussing the forms of the Basin Ranges, Davis says:*

> "The body of each range is usually continuous, although it may be incised by sharp cut valleys; if the ranges were the residuals of a period of undisturbed erosion long enough to have permitted the excavation of broad intermont valley-lowlands, each range should be divided into isolated mountain groups by the opening of wide branch valleys in its mass."

It is thus evident that the fault-blocks of Shan-tung are further advanced in their erosion cycle than are the similar masses of the Basin Ranges. This conclusion would follow with equal clearness if we compared the skeletonized heights of Shan-tung with the full-bodied mountains of the Great Basin.

* Davis. Science, N. S., vol. XIV, p. 459.

In transforming this comparison of forms into an estimate of relative age (and that is the object), we deal with the uncertain factors of rates of corrasion, as affected by slope and volume of the corrading streams. As regards slope, the differences are probably not notable, since in both regions gullies were initiated on steep scarps, and in growing to the dimensions of brooks and rivers they passed through the successive phases of profile determined on similar rock masses. The volume of the corrading streams is, however, a function of climate, and the possible differences between Shan-tung and the Great Basin may not be estimated with precision, except so far as similar surficial deposits have resulted from similar conditions. In both provinces, during the Quaternary, aggradation has prevailed over transportation, in the major valleys, to a remarkable degree. During that part of the Tertiary which followed the uplift of the Basin Ranges, a variable but relatively moist climate prevailed in the Great Basin, and the same is presumably true of Shan-tung, a mountainous district, which then, as now, was near the coast. These suggestions lead to the view that the two regions have not been under radically different climatic conditions; but so far as they have differed, the circumstances have been more favorable to erosion in Shan-tung than in the Great Basin. We thus reach a correction which should be applied to reduce any difference of age between the topographic features we are comparing.

Nevertheless, the contrast between the continuous ridges of the Great Basin and the separated mountains of Shan-tung is so great that climatic differences do not suffice to explain the greater effects of erosion in the latter over the former. Longer time, even much longer time, seems necessary.

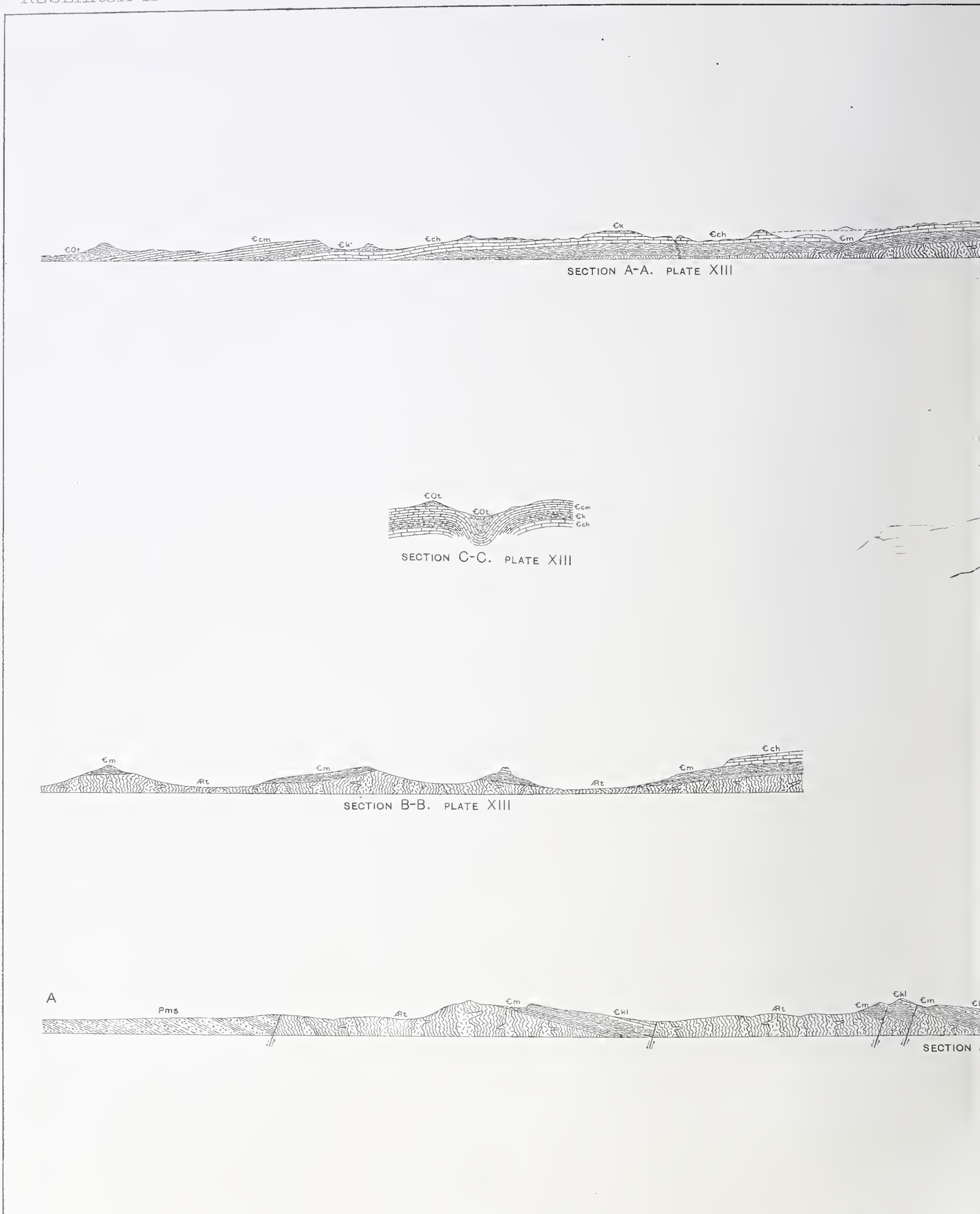
Faulting in the Great Basin region has been a persistent process, begun in the early Tertiary and continued to the present time. The major dislocations affect Eocene and Miocene strata (Esmeralda, Truckee) and Tertiary volcanics, and are assigned to the Pliocene. In comparison with these movements the older faulting of Shan-tung may have been completed before middle Tertiary time; it probably occurred during the Eocene.

This inference is sustained by similar comparisons of the Shan-tung features with other fault-scarps. The western face of the Livingston Range, Montana, is a fault-scarp of Miocene or possibly Pliocene date,* which, though severely glaciated, is still far more nearly continuous and therefore probably decidedly younger than the faults of Shan-tung. In

* Stratigraphy and Structure, Lewis and Livingston Ranges, Montana. B. Willis. Bull. Geol. Soc. America, vol. XIII, p. 344.

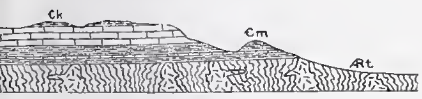
Europe, two scarps which I have seen may be cited. One is in Bohemia, between Zwittau and Mährisch-Trübau, a scarp of early or middle Miocene development which has been cut back to a notable degree, but not so far as those of Shan-tung. The other, on the lower Danube, between Milanovac and Ordova, is a fault which diverted the great river at the close of the Miocene or early in the Pliocene (Pontische Stufe) and which still rises boldly above the stream in the great limestone cliff of Velikie Strbac.

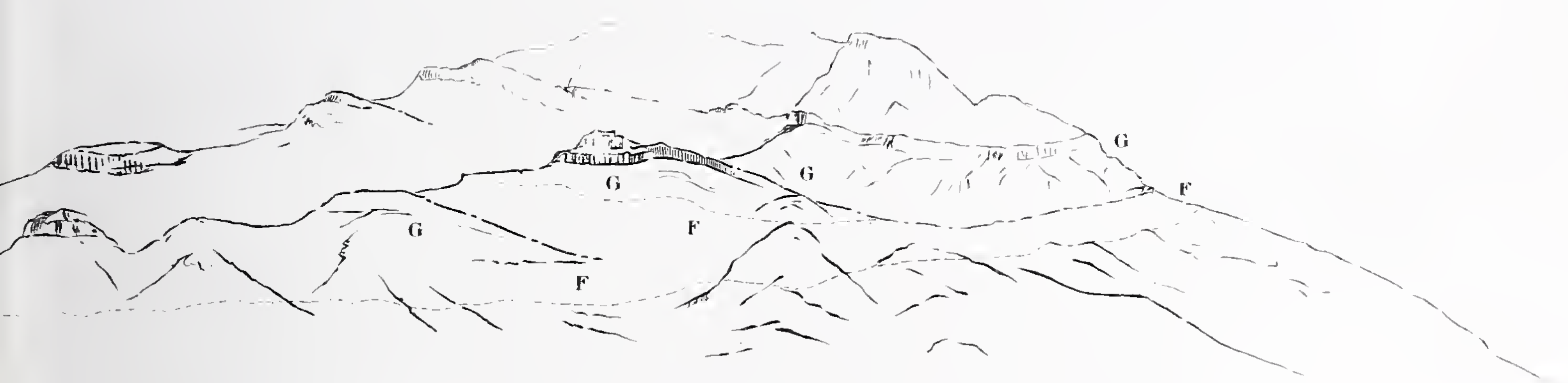
The later Eocene being probably the latest epoch during which the faulting of Shan-tung may have been completed, we are limited by physiographic considerations to a not much earlier date for the beginning of the movements. In view of the wide extension of peneplains of Cretaceous age in America and Europe, I hold it to be improbable that there are still in existence notable elevations of the surface which originated before the Cretaceous period, except such as have been buried and resurrected. Of the latter process there is no evidence in Shan-tung; on the contrary, proximity to the sea and relatively great elevation have given eroding agencies peculiar vigor. Hence I think it unlikely that the faulting began until the early Tertiary.



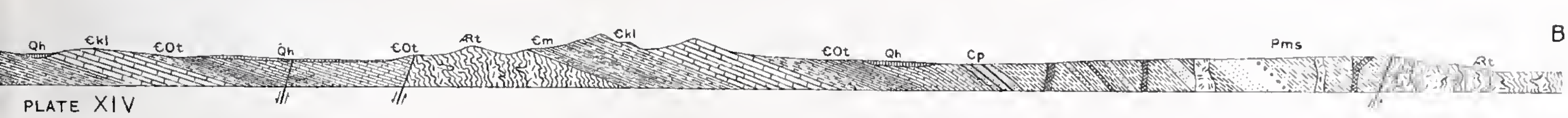
Structure Sections, Ch'ang-hia

Scale, vertical an





Sketch of the Ts'ing-ling-shan, Plate XIII; looking east; showing overthrusts in the Tsi-nan limestone.



d Sin-t'ai Districts, Shan-tung.

rizontal, 1: 90,000

CHAPTER IV.

PHYSIOGRAPHY OF SHAN-TUNG.

By Bailey Willis.

GENERAL CONSIDERATION.

Surroundings and character of the mountain district.—The mountain peninsula of Shan-tung is about 360 miles, 580 kilometers, long from northeast to southwest, and from 50 to 125 miles, 80 to 200 kilometers, wide. The sea bounds its eastern half, the coast being often bold and deeply indented. The great flood-plain of the Huang-ho, but slightly elevated above the sea, surrounds its western half and enters the mountain district in deep embayments. Thus the long and narrow mountainous peninsula descends on all sides directly to base-level.

As a mountain region Shan-tung is peculiar in the extent and arrangement of the valleys. Lowlands penetrate far into and even across the mountainous areas. The rivers meander through wide flood-plains, even near their sources. Mountains occur as isolated individuals or in groups, but only exceptionally in well-defined ranges. They vary greatly in altitude, not only in different parts of the peninsula, but in one and the same district. The distribution of altitudes is irregular and unsystematic. The highest peak, T'ai-shan, 5,000 feet, 1,500 meters, is but 30 miles, 48 kilometers, from the Yellow river and rises abruptly from the wide Wön-ho valley. Other conspicuous heights vary from 2,000 to 4,000 feet, 600 to 1,200 meters, and there are many separate lesser hills.

DESCRIPTIVE ANALYSIS.

Description of the plains and valleys.—The great flood-plain of the Huang-ho is composed of alluvial loess, brought by the river and deposited in the depression which surrounds the western end of the mountains. Before 1862 the course of the stream was to the south of Shan-tung; it is now to the north. This change, which has shifted the mouth of the river 250 miles, 400 kilometers, is typical of the migration of the stream in the past, and illustrates the manner in which it has spread the alluvium of the great plains of eastern China.

The activity of the Huang-ho is like that of other streams flowing from the mountain regions of Shan-tung. The I-ho, Wön-ho, and the many small streams which flow northward to the inner Yellow sea, have built out alluvial plains, which coalesce with that of the Huang-ho and extend the surrounding lowlands.

As we approach the mountains from Tsi-nan-fu, or elsewhere from the flood-plains, we first encounter isolated hills of hard rock, which rise abruptly from the surrounding alluvium like islands from the sea. These outliers east of Tsi-nan-fu are 4 miles from the foot of the larger mountain mass behind the city. Advancing among the hills, we find that all the valleys, even the smaller ones, are filled with alluvium, which often extends not only to but across a divide, and thus connects the drainage basins of different streams. Irregular mountain masses of considerable height and extent are thus completely isolated in the accumulations of loess. This characteristic is well shown in the special topographic map of the Ch'ang-hia district (Plate XIII).

The route from Tsi-nan-fu to T'ai-an-fu passes through this district, up the valley of the Shan-ho or Yü-fu-ho, directly toward the great T'ai-shan. One might expect to find a sharp and perhaps elevated divide at the head of the stream, on the line of the T'ai-shan ridge, but the valley maintains its width, and the divide is across a broad alluvial plain, largely made up of granite sand washed down from the ravines of the adjacent mountains. The descent to the flood-plain of the Wön-ho is very gradual.

The valley of the Wön-ho in the vicinity of T'ai-an-fu is about 15 miles, 25 kilometers, wide, and extends as an intermontane plain far to the eastward toward the head of the stream. Isolated hills rise from it, and toward the head waters become more numerous and larger, till the branches of the stream wind among mountain groups; but even there the valleys are still low and have relatively wide alluvial floors, as is illustrated in the northern part of the Sin-t'ai district (Plate XIV).

The divide crossed by the highway leading southwest from T'ai-an-fu is also broad and low, but toward the summit there are outcrops of gneiss and limestone. On the head waters of the Siau-wön-ho, in the vicinity of Sin-t'ai, there is a very broad valley, partly floored with alluvium, partly a plain eroded across strata of various ages.

The railway line between Weï-hién and Ts'ing-t'au crosses the peninsula from the northern to the southern plain, in a broad depression without notable divide. This lowland through the central section divides the mountainous peninsula into two large masses, each of which is in turn divided, by many wide and branching valleys, into smaller mountain groups.

Description of the mountains.—It has already been said that continuous mountain ranges are exceptional in Shan-tung, the characteristic placing of the heights being in groups which are generally without systematic arrangement to one another. Nevertheless, there are instances in which the distinct mountains are ranged in lines and appear to be

genetically connected. One such chain of heights extends along the northern side of the Wön-ho valley, and being dominated by its principal peak, the T'ai-shan, has been called the T'ai-shan chain. Another lies southwest of the Siau-wön-ho and Tung-wön-ho, and is called by von Richthofen the Shï-mön-shan and Kiu-nü-shan. These lie respectively not far from the northwestern and southwestern margins of the mountain region, and enclose between them a V, within which the arrangement of heights is less orderly.

In general the mountains present wild and picturesque forms. As they vary in constitution, some being of gneiss or granite and others of stratified rocks, they are unlike in details, some having step-like profiles, others rising irregularly to acute pinnacles; but they are almost without exception steep, narrow, and deeply dissected. They might be termed mountain skeletons.

These forms are brought out in the topographic maps of the Ch'ang-hia and Sin-t'ai districts already referred to, but the T'ai-shan itself may be cited as a characteristic example. The summit is a wide crescent, its points turned toward the south. Its northern slope is precipitous, and ragged spurs extend from it like flying buttresses. Within the southern crescent are deep canyons, whose heads are sunk far into the heart of the mountain, and between them are sharp and narrow spurs. The crescentic crest itself is deeply gashed. The whole mountain mass has been reduced to a wall, which is crowned by pinnacles that stand like towers of a ruined castle.

INFLUENCE OF NORMAL FAULTING.

In the section on structural geology it has been stated that the central mountain region of Shan-tung is traversed by many normal faults, which cut through all the rocks of the region and undoubtedly produced features of relief at the surface, probably of a mountainous character. The date assigned to that faulting, partly on physiographic grounds, is late Cretaceous or Eocene. The degree to which the valley system and the mountain ranges that then developed still exist is of interest in its bearing on general problems of erosion.

In discussing the rate of faulting, the relation of rivers to structure was considered. The valleys of the Wön-ho, Siau-wön-ho, and Tung-wön-ho are clearly consequent, as are also the courses of many of their tributaries which flow from the upthrown to the downthrown block. Although there have been changes in the position and development of smaller streams, due to adjustment, it is true that the courses of the master streams were determined by the faulting.

Parallel to the downthrown valleys of the three Wön-ho rivers are the two great outer mountain chains of western Shan-tung. The T'ai-shan is the upraised margin of that northwestern section of the mountain region in which we observed no local faulting,* and the range of the Shï-mön-shan and Kiu-nü-shan is likewise the elevated part of the great fault-block, whose depressed northern margin is seen at Sin-t'ai. Within the Sin-t'ai district the highest mass is that of the Lién-hua-shan, on the upthrow side of the fault Nf. The Kiu-lung-shan and Huang-yang-shan are similarly elevated masses adjacent to the valley, which corresponds to the downthrow along the fault Ng. The maze of faults in the central part of the district does not agree with any arrangement of topographic features, but along the great fault Na the hills which lie on the upthrow side represent, topographically as well as geologically, the effects of displacement.

There is thus in the relation of heights as well as of valleys that connection with normal faults which we would expect in case the relief due to faulting still survived.

Adjustment of relief.—Although the principal features of relief are effects of normal faulting, the relation is by no means so obvious as it is in regions where displacement is of more modern occurrence. During the development of faulting, fault-scarps of notable altitude probably rose close to the lines of the major faults, as they now do in Shan-si and Shen-si; at the present time they have retreated to such an extent that the faults lie far out in the valley, and the scarp in fact no longer exists. Where the effect of faulting was to bring a resistant limestone into contact with the much softer schist or gneiss, it often occurs that the limestone on the downthrow side now forms a ridge and that there is a minor valley on the upthrow. An example of this kind is seen 3 to 5 miles northwest of Sin-t'ai, and is delineated in the special map. It also happens that the Wön-ho conglomerate, the talus of the old fault-scarp, remains, forming a conspicuous ridge along the faults Na and Ni.

The recession of the fault-scarps has corresponded with the widening of the valleys, and they accordingly present extensive level plains. Thus, north of Sin-t'ai, the hills which represent the fault-scarp rise from the valley floor 1½ to 2 miles, 2.5 to 3.5 kilometers, north of the fault Na. It does not, however, follow that so wide a valley as that of the Wön-ho near T'ai-an-fu, which is 15 miles, 24 kilometers, across, has resulted wholly from erosion; it is more probable that this valley in particular is a graben, bounded by faults on both sides.

* Lorenz maps several dislocations south of Tsi-nan-fu and east of our route (*loc. cit.*, p. 23 and accompanying maps and profiles, especially profile A).

The recession of fault-scarps in consequence of erosion has greatly reduced the altitudes which might exist, and probably did exist, as a result of faulting. There are few, if any, differences of elevation which approach the probable vertical throw of the faults; the ridges, as a rule, present sharp residual crests; and it is evident from an inspection of the horizontal distribution of mountains and of their cross-sections that they are but the isolated remains of more extensive masses.

During the prolonged epoch of erosion, which has followed upon the development of the tectonic relief, the resistances offered by different rock masses have had an important effect upon the distribution of heights and lowlands. The adjustment of eminences to hard rocks and of valleys to soft rocks is exceedingly perfect. Among the rocks of the T'ai-shan complex the schists are somewhat softer than the granites, and the latter form bosses in extensive exposures of the series; but effects of jointing seem to be of more consequence than differences of petrographic character. The temple-crowned summit of the T'ai-shan consists of large blocks divided by but few widely spaced joint-planes. Along these joints deep clefts are developed, and the precipitous cliffs correspond with vertical faces. A similar and even more striking instance is that of the Ts'in-lung-shan southeast of Sin-t'ai. South of this hill passes the great fault Na; north of it the gneiss is minutely sheared in an east-west direction, apparently by distributed branches of the fault. The rock between the two faults is jointed on a large scale, but not sheared; the great blocks which constitute the center of the mass have so resisted erosion that they form a peak 600 feet in height, which is one of the most conspicuous features of this picturesque region.

Among the stratified rocks the Sinian limestones are the most resistant. They are interbedded with relatively very soft shales, which rapidly disintegrate and are either washed or blown away from the limestone surfaces. It is therefore common to find divides established on the edge of a limestone stratum which forms a questa, that is, a hill bounded by a cliff on one side and a dip slope of the hard stratum on the other.

Adjustment of streams.—In a stream system which retains the features of early adjustment to normal faults we should expect to find many channels situated parallel to the faults along the downthrown margins of fault-blocks; and in escaping from a depressed region, streams should cross the faults where they have least throw, or pass around their ends. It is only the master streams of Shan-tung which conform to these expectations. While the smaller streams are usually consequent, in that they flow from the upthrow to the downthrow, they cross the dislocations at right angles, and frequently at points where the throw is considerable.

This is an effect of adjustment incident to the great recession of the fault-scarps. In any region of modern faulting we observe that the scarp is more or less deeply dissected by ravines, which originate upon its steep slope at right angles to the fault, and which, by virtue of their great fall, grow rapidly into the upthrown mass. The autogenous brooks are favored by a low point of discharge and an elevated source. They take the shortest route, and in contest with those streams which flow parallel to the fault have a decided advantage. The capture and diversion of other streams to their courses is the natural result, and is associated with the establishment of divides at those points between the major fault valleys where the retrogressive work of the autogenous streams is balanced. A good example of this development of drainage is seen in the Sin-t'ai district, which happens to extend from one great fault valley to another across a watershed that is established in spite of, rather than in accordance with, the irregular structures and diverse rock types of the district.

It follows from the development of the autogenous brooks, that mountain ranges resulting from faulting are ultimately cut into sections, which, other things being equal, are of similar length. The mountain masses thus separated from one another become, as the valleys widen, isolated mountain groups; and this is what has happened in the case of the T'ai-shan chain and its counterpart southwest of Sin-t'ai. A similar but less orderly effect is observed where the faulting is more complex.

Character of relief before faulting.—In the study of physiographic features it is often true that the summits of elevations are found to exhibit features of a previous topographic cycle, which have not yet been obliterated by the subsequent effects of deformation and erosion. Where such an older cycle reached the development of a peneplain, flat remnants of the plain may sometimes be detected; or, when this is not the case, there may be a constant relation of heights on rocks of unlike character, which justifies the inference of its former existence. During our journey in Shan-tung we searched for evidence of an older topographic surface than that which is now developing, but failed to find it. The skeletonized mountains bear no flats which might be considered remnants of an ancient plain; the former relief, whatever it was, has been so modified by faulting and erosion that its character is no longer expressed in the existing topography. We are thus without means of determining definitely the topographic aspects of the province prior to faulting. There is, however, basis for an inference. The surfaces of the upthrown blocks do not exhibit conspicuous peaks, rising high above their general elevation, as they probably would had there been great mountains before the faulting occurred. The downthrown areas are flattish. This flatness is, no doubt, in large

part an effect of valley erosion following faulting, yet the process would probably not have obliterated large features of earlier relief. Hence we infer that before the present mountains originated in faulting, Shan-tung was a land of moderate relief; a hilly country possibly, but probably not mountainous; its relative altitudes measurable perhaps in hundreds of feet, but not in thousands.

WARPING.

*Evidence of warping.**—The peninsula of Shan-tung may be considered as a whole, with reference to the surrounding regions, as an elevated area encompassed by the depressions which are occupied by the sea and by the alluvium of the Huang-ho delta. Thus viewed it is an irregular dome, having a greatest altitude of 5,000 feet above sea-level; or, if we strip off the alluvium and marine deposits from the surrounding areas, it is a dome rising somewhat more than 5,000 feet above the bottoms of the adjacent hollows. The natural profile of this dome is a very low arch, little more than 1 mile high and 120 miles across.

The surface thus defined is that of the Pre-Tertiary rocks; in the absence of late Mesozoic sediments it is believed to have been a surface of erosion in Mesozoic time, and to have been a lowland or low hill land prior to the displacements which initiated the present relief. If this be so it can not have had its present form or relations to sea-level; the elevations must have been modified by faulting, or by warping, or by faulting and warping combined.

Effects of faulting are obvious in the central part of the province. Marginal faults are not established. Von Richthofen describes one near Tsi-nan-fu, on the ground that hills of igneous rock occur on a level with supposedly nearly horizontal strata of Sinian limestone. Since the distance between the outcrops is 4 miles, 6.5 kilometers, and the Sinian strata dip outward under the alluvial plain, the relative positions of the two rock masses may, with greater reason, be accounted for without dislocation; and the presence of dikes in the Sinian, described in the section on stratigraphy, shows that eruptives may be found anywhere in the system. Furthermore, large igneous masses are known chiefly in the higher horizon, above the coal-bearing Po-shan formation. The northward dip of the Sinian near Tsi-nan-fu would lead one to anticipate the occurrence of the Po-shan and the associated igneous rocks beneath the plain, where these isolated hillocks occur. In this respect the occurrence of the igneous rocks is indica-

* Warping is here used to designate the process of change of form and altitude of the surface due to vertical movements of the subjacent rock masses. It is often associated with normal faulting.

tive of a continuous rather than a faulted section. Comparison may be made with a section through the Huang-yang-shan of the Sin-t'ai district.

The presence or absence of peripheral faulting may be indicated by physiographic facts. The maturely eroded surface of the mountain region extends down to the alluvial plains in groups of hills. If these are abruptly cut off along a well-defined face, the existence of a fault may be reasonably assumed; if the hills terminate with an approximate alinement, even though they be separated by deeply eroded valleys, faulting may be considered probable. If, on the other hand, the hills lessen in height toward the plain, extend irregularly into it, and become more and more isolated, we infer that the sculptured surface is continuous beneath the alluvium. So far as we have seen the marginal relations of the Shan-tung mountains in the vicinity of Tsi-nan-fu and of Po-shan, the latter relation is the existing one.

Warping is the alternative to faulting. That is to say, the margins of the dome may be bent down instead of broken down. As stated in the preceding paragraph, the physiographic evidence indicates this relation. In the absence of demonstrative evidence of peripheral faulting, and in view of the long peninsulas and islands of hills which extend out into the sea and plains, it is most probable that the difference in elevation between the height of the Shan-tung dome and the depths of the surrounding depressions is an effect of warping. It will appear in discussing the effects of warping and faulting in Central China, that a normal fault may arise upon a steeply warped surface and form its longitudinal continuation. Warping, therefore, does not exclude faulting, but it is believed to be more generally the fact about the peninsula of Shan-tung.

Date of warping.—If we compare the physiography of the marginal districts of Shan-tung with that of the interior, we find that they are of closely similar character and in like stages of development; considering the nearness of the districts, the identity of the rocks, and the sameness of the activities of erosion, there can be no doubt but that the marginal and central features are of similar age; and this conclusion extends to the buried surfaces beneath the present level of the plain. As the marginal sculpture must have developed at a higher level than that which the surface beneath sea-level now occupies, it follows that the process of warping began (or continued) and resulted in the depression of the margin after the present physiographic type had been established. Warping is thus recognized to be a relatively modern effect.

The depressions which surround Shan-tung are floored or filled with sediments, which began to accumulate as soon as any part of the surface sank to the level of aggradation by rivers, or below sea-level. If we could

get at the deeper deposits we could probably fix the date of beginning of warping; but no deep wells have been sunk, and throughout the plain only recent alluvium is to be seen. The latest deposits cover all earlier ones, partly in consequence of the abundant sediment derived from the loess, and also because continued subsidence has brought a wider area down to the level of the flood plains.

Shan-tung a horst.—Has recent warping resulted in elevation or depression of the central mass of the dome? In Shan-tung the answer to this question appears to be that the central mass has remained at a fixed altitude with reference to sea-level, while the margins have been depressed.

We have seen that the principal differences of elevation in the western mountain district of Shan-tung are the results of faulting, which date from an early Tertiary time, and which have been modified by prolonged erosion. Partly in consequence of faulting and partly as a result of erosion, the valleys are very broad and low. They could not have been eroded to the present level had the mountain area formerly stood notably lower than now; neither could they have retained flat and aggraded valley floors if the area had recently been elevated. The condition of the valleys proves that, for a long period, the mountain district has remained nearly fixed with reference to sea-level. It has been a true "horst." During part of this cycle of erosion, and up to the latest, if not to the last, episodes, the surrounding districts have subsided; they have been warped down.

Thus the mountain region of Shan-tung may be described as a horst surrounded by downwarps.

CHAPTER V.

RECONNAISSANCE IN SOUTHWEST LIAU-TUNG.

By Eliot Blackwelder.

INTRODUCTION.

It was a part of the original plan of the expedition to begin the explorations in China with a detailed investigation of certain districts in southern Manchuria, particularly the region southeast of Mukden and south of Kai-p'ing-hién. In 1869 Baron von Richthofen made an extensive journey through this portion of the province. He found that the mountains contained Cambrian sedimentary rocks, widely distributed and in comprehensive stratigraphic sequence. Furthermore, the rocks were but little disturbed and not at all metamorphosed. On the basis of this information the province was selected as offering the most favorable opportunity for a careful study of a prominent phase of the Cambrian rocks of China.

It was found, however, upon reaching China, that it was not advisable to attempt geological surveys in Manchuria, in view of the existing international relations and the disturbed condition of the country. We therefore made Shan-tung the field of research during the autumn months, with the hope of going into Manchuria at some subsequent season.

In December it was decided to make a brief reconnaissance in Manchuria, as a preliminary to a more detailed investigation in the spring, and I was thus employed during the latter part of the month, accompanied only by Li-san (Chinese interpreter).

Von Richthofen had found beneath the fossiliferous Cambrian rocks a series of red sandstones, called by him the "Yung-ning Sandstein," which he believed to be somewhat older than any of the Sinian strata in Shan-tung. He was unable in his rapid journey to give this formation a careful investigation, and he did not find in it any traces of fossils. It was hoped, however, that we might succeed in discovering there a fauna older than the Lower Cambrian fauna (Redlichia zone) of central Shan-tung. The region to the west of the railroad, on the west coast of Liau-tung, was chosen for this reconnaissance on account of the excellent development there of the Yung-ning sandstone. It happened that this was a very fortunate choice at that time, inasmuch as the mountains to the eastward were infested by bandits.

ITINERARY.

I left Tientsin with Li-san on the 19th of December, taking the railroad to Yin-k'óu (Niu-chuang). Leaving Yin-k'óu on the 21st of December via the Chinese-Eastern (Russian) railroad, we reached the station of Pu-lan-tién (known on British charts as Port Adams) the following morning. Here carts were obtained and a rapid journey begun toward the northwest, shifting to north and northeast. The road which we traveled passed through the villages of San-kua-miau, Ting-t'un, Wu-kia-tién, Ma-tién-tzï, and Ïr-shï-li-p'u, to the city of Fu-chóu; thence it took a northeasterly direction through Yen-kia-tién, Tsau-kia-tién, Li-kuan-ts'un, and reached the railroad again at Siung-yüé-chöng. Arriving on the night of December 25th, we returned by rail from this station to Tientsin.

The route followed will be seen to be almost identical with that traveled by von Richthofen, in the portion from Fu-chóu to Siung-yüé-chöng. South of the former city, however, his road lay considerably to the southwest of ours, joining it again only at our starting point, Pu-lan-tién.

GEOGRAPHIC FEATURES.

East of the railroad there are rugged mountains with a relief of 2,000 to 4,000 feet, 600 to 1,200 meters, in which igneous and metamorphic rocks evidently predominate. To the west, however, in the district studied, a low hill country or dissected upland stretches westward to the sea. Between Pu-lan-tién and Fu-chóu low hills of shale and sandstone, with occasional higher ridges containing quartzites and limestones, are more or less isolated from each other by broad sandy flats, most of which are the valleys of intermittent streams. To the south we saw low but precipitous mountains, apparently composed of limestone. From Fu-chóu to Li-kuan-ts'un there prevails an undulating upland of less than 200 feet, 60 meters, relief, which marks the outcrop of the Yung-ning sandstone. Immediately north of Li-kuan-ts'un hard quartzites, with marble and schists, maintain a ridge 600 to 800 feet, 120 to 240 meters, high, beyond which the plain continues northward over deeply weathered igneous rocks.

The peninsula of Liau-tung has the irregular and embayed valleys which are characteristic of a recently submerged land. The mountains east of the railroad are in advanced maturity in the present cycle of erosion. Their rugged peaks, like those of Shan-tung, fail to suggest any earlier cycles. The district lying to the west of the railroad is a low piedmont belt, sloping gently from the mountains to the sea. It also has reached advanced maturity in its erosion history. The valleys, which are broad and nearly flat-bottomed, have been submerged at their lower ends, allowing the sea in many cases to penetrate inland. The slackening of the

streams, brought about by this subsidence, has initiated a period of aggradation. All of the streams are now engaged in silting up their valleys, and are pushing back the heads of the inlets as their flood-plains are extended sea-ward by constant additions of material. The rapidity of this progress is strikingly indicated by the present situation of certain towns, which, within three or four centuries, were seaports, but which are now some miles from the coast. One of these, Siung-yüé-chöng, is said to have been a port of entry of considerable importance during the Ming dynasty (A. D. 1368 to 1625); the city is now nearly deserted, and the head of its former harbor lies 4 miles to the west of it.

GEOLOGY.

INTRODUCTION.

Observations made in the course of a rapid journey, which did not permit extensive digressions from the road, must necessarily include errors and uncertainties. In this particular trip the difficulties were somewhat increased by the frequent recurrence of sandy flats and by the prevalence of a mantle of soil over the bed-rock. It was, therefore, frequently impracticable to determine the limits of such formations as were recognized, and the entire failure of all efforts to find fossils left me in doubt as to questions of age. The following section, therefore, is indefinite as to thickness, limits, and geologic age; it represents merely a reasonable interpretation of such facts as are available:*

5. Volcanic rocks: intrusions (and possibly extrusions) of basalts, porphyries, etc.
4. Fu-chóu series: earthy sandstones, quartzites, argillaceous limestones, and shales, mostly of green, gray, and purplish colors. Probably of Cambrian age.
3. The Yung-ning sandstone: earthy sandstones, sandy shale, and conglomeratic sandstone—all of reddish or brown colors. Probably Lower Cambrian.
2. The Ta-ku-shan series: quartzite, marble, and slates. Probably Algonkian.
1. Gneissic complex: gneiss, schists, granite, etc., including the granite near Siung-yüé-chöng. Probably Archean.

STATEMENT OF OBSERVATIONS.

Gneissic complex.—Rocks of the basal complex were encountered in two localities only. The first exposure occurs about 4 miles, 6.8 kilometers, northwest of Pu-lan-tién and is something more than a mile in breadth. The rock is biotite-gneiss of rather fine grain, into which have been intruded dikes of gray granite associated with veins of pegmatite and quartz. A single large dike of basalt was found cutting through this complex, and as it is not metamorphosed it is probably of much younger age. This exposure is obscured along its southern border by sand and

* The difficulties in the way of making a satisfactory study of this area in the course of a rapid journey are eloquently set forth by von Richthofen in his report. (China, vol. II, pp. 109, 110.)

soil derived from unknown sedimentary rocks, while the northwestern side is bounded by the Fu-chóu series.

In the vicinity of Siung-yüé-chöng, and thence southward to the edge of the hills, the bed-rock is a massive gneissoid granite, which consists of biotite, smoky quartz, and the usual feldspars. The texture is moderately coarse, but not porphyritic. In this locality the granite is deeply decayed, being so soft at the surface that the roadways have been worn into it to a depth of several feet, just as elsewhere in China they have been lowered in the loess. With the exception of a few dikes of porphyry and basalt and still fewer veins of pegmatite, no other rocks were found associated with the granite. The facts observed in this locality do not serve to determine the age of this granite or granite-gneiss; on the north the exposure was lost under the alluvium of the valley; on the south it is in contact with more recent lavas. In addition to the gneiss, von Richthofen discriminates gneiss-granite and Korea granite. The latter contains hornblende and is markedly porphyritic; it is also devoid of gneissic structure. The Siung-yüé granite seems, therefore, distant from the Korea granite. The gneiss north of Siung-yüé-chöng is described by von Richthofen as varying from a true mica-gneiss to granite in which the schistose texture is absent.* From this we may infer that the mica-granite of this locality is a part of the basal gneissic complex and is comparable to the granites belonging to the T'ai-shan complex of Shan-tung.

Ta-ku-shan series.—This series of metamorphic rocks, which is reported by von Richthofen from many places in Liau-tung, came to my notice in two localities only. In the hills immediately east of the Russian station at Ta-shï-k'iau, white quartzite dips 40° to 60° toward the south. This member, which appears to be about 300 feet thick, forms the crest and southern slope of the hill. For the most part the rock is pure and well consolidated, but it includes thin local strata of sericite-schists, which probably represent shaly partings in the original sandstone. Beneath the quartzite appears marble, which was quarried at that point by the Russians for the purpose of making lime. It is usually a gray, finely crystalline rock banded with dark colors, but there are also layers of considerable thickness which are of pale flesh color. Underneath the calcareous member, argillaceous schists appear in conformable relation to the marble. This lowest member comprises black argillites which are in places slaty, a hard maroon-colored slate, and crumpled gray phyllites containing numerous small red spots, which originate from the weathering of magnetite crystals. What lies beneath these schists was not observed, nor was the series found in contact at this point with rocks of different age.

* "Er (Gneiss) geht zuweilen in Gneissgranit über, in welchem die schieferige Textur bis zu Unkennbarkeit zurücktritt." (China, vol. II, p. 72.)

The succession of quartzites, marble, and schists, which occur in the ridge just north of Li-kuan-ts'un, is so like that at Ta-shï-k'iau that we may consider them as all belonging to a single system. The first member is a massive gray quartzite, which differs from the similar rock seen at Ta-shi-k'iau in that it contains numerous local layers of conglomerate. The pebbles rarely exceed the size of hazel-nuts and are composed, for the most part, of quartzes which are somewhat varied in color; white, gray, brown, and even red. As the base of the hill was obscured by soil and debris, I could not determine whether or not the conglomerate marks an unconformity at the base of the quartzite. It is, however, significant that in the considerable vertical range through which the conglomerate was traced, it did not appear to grow coarser or more prevalent downwards. The marble is white and in that respect is unlike the marble of Ta-shï-k'iau. Furthermore, it contains aggregates of needle-like crystals, which are probably tremolite; it is not improbable that this feature is a result of contact metamorphism, for the limestone happens to be associated, in the few exposures examined, with dikes of hornblende porphyry. The mica-schists are so deeply decayed that it was not practicable to determine their exact character.

This series was observed while ascending the small valley which joins the river just north of Li-kuan-ts'un.* The quartzite is exposed in the bluffs at the mouth of the ravine, in massive layers which have an inclination of 25° toward the south. The soil-covered slopes of the valley do not afford many exposures of the bed-rock. After crossing the quartzite we came upon the marble dipping southward and apparently underlying the quartzose member; the relations of the two, however, were not accurately visible. The marble is in turn succeeded by the schists, which underlie the gentle slopes near the head of the valley.

The relations of the metamorphic rocks to the other systems are shrouded in the same uncertainty as those of Ta-shï-k'iau, inasmuch as the southern border of the outcrop is bounded by a sandy flat, while porphyry intrusions inclose it on the north.

Yung-ning sandstone.—The type locality for von Richthofen's Yung-ning sandstone was crossed between Fu-chóu and Li-kuan-ts'un. The description already given by von Richthofen† in his report on this district is ample for all the details observed. For the most part the rocks consist of coarse sandstones, grits, or graywackes, which are cross-bedded in

* Although von Richthofen passed over the same road he was prevented by darkness from making observations in these hills. (Vol. II, p. 72:—Leider zog ich nach Sonnenuntergang vorüber und konnte daher die Zusammensetzung dieser Hügel nicht ermitteln.) His section has since been found incorrect as far as concerns the structure of the rocks near Li-kuan-ts'un. (China, vol. II, p. 74.)

† China, vol. II, pp. 73, 109.

intricate forms. In composition they are usually earthy and are often rich in feldspars. Although prevailingly soft and friable, the rock is locally cemented into a quartzitic arkose. The sandstone varies in the one direction to shaly sandstone and even to thin local shales, and on the other hand it grades into conglomeratic sandstone and typical conglomerate. Of these two extreme phases the conglomerate is much the more prominent. The pebbles consist almost entirely of quartz and chert of various colors, with occasional fragments of granite. In size the fragments rarely exceed the diameter of 6 or 7 centimeters and are usually much smaller. All of these sandy rocks are prevailingly red or maroon in color, with variations toward dull brown and yellowish tints. Numerous dikes of igneous rocks, which are described in later pages, have been intruded through the sandstone at various points.

Throughout most of this area the bedding of the sandstone is nearly horizontal. On account of the cross-bedding, observations of the dip must be made with care and discrimination; but where the major stratification planes are apparent the dip is seen to be undulatory, varying from maxima of 30° northeast and 25° southwest. On the extreme southern border of the exposure the rocks dip to the northeast, while in the last outcrops visible on the northern edge the strata dip gently southward. The general structure, therefore, is that of a flat synclinorium.

On the north side, the Yung-ning sandstone, as exposed, is separated from the metamorphic rocks north of it by massive porphyry intrusions and a flat sandy valley; the relations, therefore, could not be observed directly. The conglomeratic quartzite of Li-kuan-ts'un seems to belong more appropriately with the white crystalline limestone and schists upon which it appears to lie, than with the Yung-ning formation. It not only lacks the red color of the sandstones, but it is much more thoroughly consolidated than they are. As already stated, von Richthofen crossed this range after nightfall and therefore could not see the geologic features of the hills. His inference that the rocks belonged to the Yung-ning formation, which appears south of Li-kuan-ts'un, is probably erroneous.

On the southern border of the exposure of the Yung-ning sandstone the lowest member of that formation, to a thickness of about 50 feet, consists of coarse conglomerate. The pebbles average nearly as large as hen's eggs, scattered individuals having a diameter of as much as 4 inches. As in the conglomerates in the higher horizons in the sandstones, these pebbles are composed of quartz, quartzite, and chert. The matrix is quartzite and is so rich in ferric oxides that it presents a deep reddish-brown color, like the rest of the sandstone. Toward the base of the member the pebbles become larger and more closely crowded—a common characteristic of basal conglomerates. This conglomerate, which, by virtue of its superior

resistance, stands out from the lowland in a prominent series of hills, lies directly upon the upturned edges of the limestone and shale series, which is described later as the Fu-chóu series. In the vicinity of the contact the shaly strata are steeply inclined toward the south, and the rocks are full of local contortions and slickensides. The occurrence of the conglomerate lying with discordant stratification upon the limestones raises the hypothesis that we are dealing with an unconformity, the Fu-chóu series being in that case older than the Yung-ning. But von Richthofen reports that he found the red sandstones lying conformably beneath the Fu-chóu series in several localities. He says: "I have numerous cases to cite in which I carefully investigated the stratigraphy of these red sandstones, and was able with positive certainty to determine their age relative to the strata with the principal primordial fauna."* This information, coupled with the evident local deformation of the limestones at this contact, indicates that the conglomerate was not deposited upon the limestones, but has been overthrust upon them from the north. The quartzitic rock, being the most rigid in the series, would naturally determine the locus of the overthrust.

If the relation is that of an overthrust, an inference as to the age of the Yung-ning sandstone must depend upon the statement of von Richthofen, quoted above, that it lies conformably beneath Cambrian limestones and shales.

No traces of organic remains have yet been found in the formation, nor are they to be expected in any noteworthy quantity in such a deposit. The heterogeneous composition and cross-bedding of the sandstone indicate that it was formed in very shallow water, either along a seashore, or in a lake basin, or even by shifting streams operating upon the land surface.

As to the probable thickness of the red sandstones, the conditions in this particular area afford but little evidence. On account of the undulatory bedding, the average of which is equivalent to horizontality, a thickness of a few hundred feet would suffice for the local occurrences. From his observations in several localities, von Richthofen estimates that the formation is at least 2,000 feet, 600 meters.

Southeast of Fu-chóu there is another exposure in which sandy rocks are prominent, and this is evidently an eastward continuation of what von Richthofen considered a second outcrop of the Yung-ning sandstone. Here the strata are, however, markedly different. The sandstone which I observed in this area had few, if any, of the distinguishing characteristics of the Yung-ning formation. The colors are white, grayish, or yellowish, but never red; the bedding is regular, and conglomerate was not observed

* China, vol. II, p. 73.

in any of the outcrops. Furthermore, one member of this series is a massive pure quartzite, something not seen in the Yung-ning sandstone as developed north of Fu-chóu. The quartzite is associated with soft clay shales of variegated colors; these also are unknown in the original section of the Yung-ning formation. The data for definite correlation with any other series are not available, but such observations as were made point rather to a connection between these sandstones and the Fu-chóu series, which outcrops on both sides of them, and we have, therefore, included them provisionally under that name.

Upon von Richthofen's map the Yung-ning sandstone is represented as extending from the Fu-chóu-ho southeastward to Pu-lan-tién. This mapping is, of course, hypothetical, since the author's own route lay somewhat to the southwest; and along a nearly direct line connecting Fu-chóu and Pu-lan-tién the geology was found to be somewhat different. Southeast of the belt of sandstone, quartzites, and shales just mentioned, there is an exposure of the Fu-chóu series, which trends northeastward, as do the others. Immediately northwest of Pu-lan-tién the valleys are heavily aggraded, exposures of rock are few and obscured with soil; at several points, however, the bed-rock was observed. In one instance it was found to consist of soft greenish shales; in another of very siliceous buff limestone; while in a third case the character of the soil indicated the presence of white quartzite. To just what series these isolated masses may belong is a matter of conjecture. It is fairly certain that they are not to be classed with the Yung-ning sandstone, but more probably with the Fu-chóu series.

Fu-chóu series.—For the succession of gray and green calcareous and shaly rocks, apparently overlying the Yung-ning sandstone, we shall use the name Fu-chóu series, believing it safer to do so than to extend from Shan-tung the term "Tung-wön" series, used by von Richthofen. The Fu-chóu series also includes certain members, which do not appear in his section of the "Tung-wön Schichten" in Liau-tung. The only exposure of these rocks which came to my notice lies between the southern edge of the Yung-ning sandstone near Fu-chóu and the gneissic outcrop near Ting-t'un. In this district there are several wide sandy valleys, which run parallel to the strike of the rocks and therefore conceal certain members of the series. The existence of overthrust faults adds to the uncertainty regarding the facts of the stratigraphy.

The member which appears to be lowest in the series is the quartzite, which lies upon the gneiss at the southern edge of the exposure. This member is a pure gray quartzite, about 100 feet, 30 meters, thick, without conglomerate. The contact between the quartzite and the gneiss was not

quite exposed, but there are fault-planes in the lower layers of the quartzite which have the same inclination as the contact itself, and suggest the inference that the quartzite is overthrust upon the gneiss.

Upon the quartzite lie at least 100 to 200 feet, 30 to 60 meters, of soft shales. Near the base these shales are sandy in composition, with gray and olive colors; higher in the sequence they are brownish and greenish, with occasional maroon-colored layers. Above them we found an alternation of olive and yellowish calcareous shales with gray, green, or buff limestones, calcareous argillites, and green and purple shales. The purple shales are in turn succeeded by a friable green grit, or earthy sandstone, which contains numerous thin beds of green shale. This phase of the formation prevails northwest of Wu-kia-tién, the strata lying in gentle folds. Some miles to the northwest more shaly limestones appear, as if overlying the shales and greenish sandstone; the wide alluvial flat which follows makes the relations of these and succeeding outcrops very uncertain. A prominent range of hills trending northeast-southwest is maintained by a member of white quartzite, grading upwards into sandstone, which appears buffish in weathered outcrops. On the southeast slope of the hills olive, brown, and yellow shales occur beneath the quartzite. To the northeast, after crossing the valley of the Fu-chóu-ho, additional outcrops of pure buff-colored sandstone were encountered. The strata dip gently northwest, parallel with the quartzite, and are supposed to overlie the latter. What intervenes between the two horizons I could not observe. In the hills immediately north of Fu-chóu the greenish argillites, limestones, and variegated shales, with thin interbedded quartzites, appear in highly inclined position. At this point, as already described, they are apparently overthrust from the north by the Yung-ning conglomerate. Farther to the east, however, where the ridge was crossed by von Richthofen, the overthrust was not observed.

The limestones and shales in this series were carefully searched in several places for fossils, but no traces of them were detected. It is also noteworthy that no igneous dikes were seen in this belt, although they are quite common to the north of it.

We have no adequate data for estimating the thickness of the Fu-chóu series. The strata are moderately folded, and in some cases highly tilted and contorted; and the existence of overthrusts is probable, though none were observed.

On account of the absence of fossils and the unsatisfactory structural relations of the Fu-chóu series to other formations, we must rely upon von Richthofen for an opinion as to its age. He reports finding the series conformable beneath rocks which contain Cambrian fossils.* He also

* China, vol. II, p. 110.

considers this series equivalent to the rocks exposed along the Tung-wön-ho in Shan-tung—a section which apparently contains portions of our Man-t'o and Kiu-lung formations.

Volcanic rocks.—Sedimentary rocks younger than the Fu-chóu series were not observed along my route of travel, although Carboniferous strata were seen by von Richthofen in his journey toward the southwest. The youngest rocks which came to my notice are certain intrusive lavas, occurring mostly in the northern part of the region studied.

At the village of Li-kuan-ts'un, and again on the northern slope of the ridge to the north of that village, there are massive intrusions of dark purplish-brown feldspar-porphyry. The form of these intrusions is suggestive of volcanic stocks, but if this inference is correct, the old volcanoes have been entirely destroyed, for I saw no other lava flows nor other superficial accumulations. Two to 5 miles, 3 to 8 kilometers, south of Li-kuan-ts'un the sandstone is cut by a variety of dikes, which are in some places exceedingly numerous. From inspection in the field the rocks appear to be gray quartz-porphyries, light brown feldspar-porphyries, aplites, and dark greenstones. The intrusion of these dikes has had but little effect upon the sandstone. North of Li-kuan-ts'un there are a few dikes of greenish hornblende-porphyry, rhyolite-porphyry, and greenstone, which break indiscriminately through rocks of various ages. Other dikes of a similar nature are found near the southern border of the Yung-ning sandstone outcrop north of Fu-chóu. In the exposure of the gneissic complex northwest of Ting-t'un, a dike of unaltered basalt nearly 100 feet, 30 meters, thick traverses the ancient rocks.

All of these lavas are relatively unaltered, except as they have undergone weathering at the surface. Lithologically, they appear to be similar to many of the dikes associated with the Carboniferous and later rocks of central Shan-tung.

CORRELATION OF SERIES.

The formations found in southwest Liau-tung are prevailingly unlike those of western Shan-tung and western Chï-li. The sedimentary series contain many unfamiliar members whose positions in the general column were not determinable.

Gneissic complex.—The basal complex in this region is so much like that of Shan-tung, that it may safely be considered its equivalent. The granite at Siung-yüé-chöng, which I have correlated provisionally with the complex, is not unlike some of the granites of the T'ai-shan system. It appears to differ notably from the "Korea granite" which von Richthofen describes* and assigns to a period later than the Ta-ku-shan quartzites, etc.

*China, vol. II, pp. 83, 107.

Ta-ku-shan series.—The advanced metamorphism of these quartzites, marbles, and schists indicates that they are older than the unmetamorphosed Paleozoic rocks. This view is corroborated by von Richthofen, who observed the Sinian limestones and sandstones lying unconformably upon the metamorphic series.* In northern China proper we distinguished two sedimentary systems of Pre-Cambrian age, and it may be supposed that the Ta-ku-shan system is the representative of one or the other of them. In comparing it with the Hu-t'o series, we find that the Ta-ku-shan is more severely metamorphosed, and lacks the flinty limestones which are so characteristic of that series. The Ta-ku-shan rocks more nearly resemble certain portions of the Wu-t'ai series of Shan-si, which, like them, contains marble and quartzite associated with schists; but the data are not yet sufficient to establish a correlation.

Yung-ning sandstone.—Von Richthofen's observations remain the principal data available in regard to the stratigraphic relations of the Yung-ning sandstone. He describes it as underlying the Fu-chóu series, which in turn he found beneath strata containing Upper Cambrian fossils. The Fu-chóu series, which von Richthofen correlated with his Tung-wön (our Man-t'o and Kiu-lung) seems to represent Middle Cambrian; but the Fu-chóu strata do not include any of the red rocks elsewhere so characteristic of the Man-t'o or Lower Cambrian. The Yung-ning sandstone is red and apparently occupies, in relation to the Fu-chóu, the position which the red Man-t'o holds with reference to the Kiu-lung. On this basis we provisionally regard the Yung-ning as a local and probably littoral phase of the Man-t'o formation.

Fu-chóu series.—This series, like the Yung-ning, has failed to yield any fossils. Von Richthofen says that it rests upon the Yung-ning sandstone and underlies dark Upper Cambrian limestones, which are in turn followed by the so-called "Kohlenkalk" (the Tsi-nan limestone of Shan-tung).† The dark Cambrian limestones were identified by means of numerous fossils. He considered the Fu-chóu series equivalent in age to his "Tung-wön Schichten" near I-chóu-fu in Shan-tung.‡ This is a succession of reddish shales and sandstones, with thin-bedded nodular and oolitic limestones. Judging from our own studies in Shan-tung, I infer that the sequence of the Tung-wön-ho contains portions of the Man-t'o shale and the Kiu-lung limestones, but the section has been interrupted by faults and igneous intrusions, so that the order of succession is unreliable. In that phase of the Fu-chóu series, which occurs along my route in Liau-tung, there is little to remind one of either the Man-t'o or the Kiu-lung

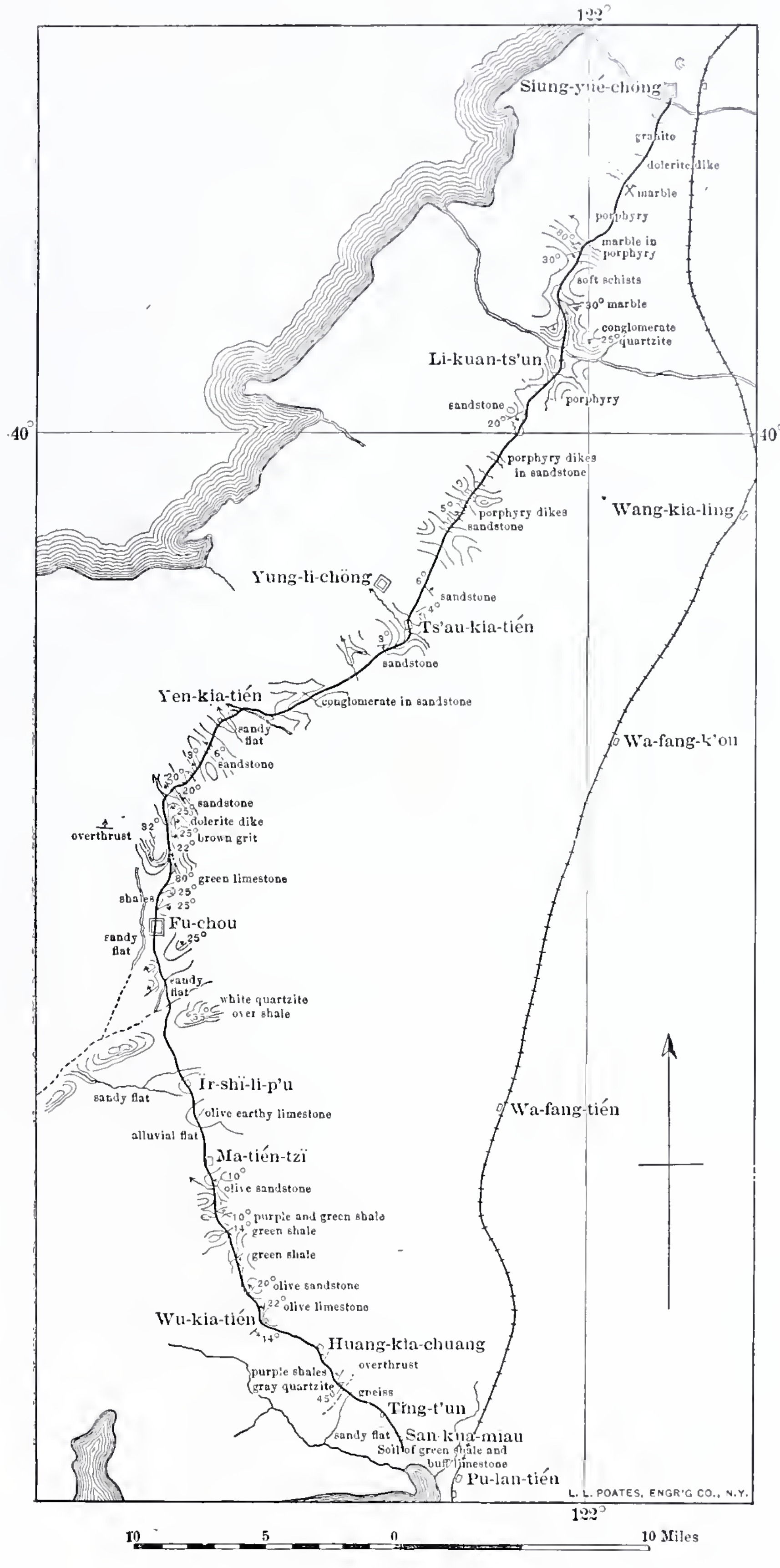
*China, vol. II, pp. 98, 100. †Ibid., pp. 79, 80. ‡Ibid., pp. 187, 188.

groups; the variegated shales and some of the argillaceous limestones resemble certain members of the Man-t'o, but here the likeness ends. On the other hand the Man-t'o formation furnishes no counterpart for such members of the Fu-chóu series as the white quartzite, yellow sandstone, greenish grit, and hard greenish limestones. We are inclined to think that in Liau-tung we have to deal with a local lithological development of the Cambrian different from that which characterizes western Shan-tung. It is probable that the Fu-chóu series constitutes a part of the Cambrian system, but any present attempt to make a more definite correlation must necessarily be unreliable.

Volcanic rocks.—The intrusives observed along my route of travel invade the Yung-ning sandstone and underlying rocks. On the basis of other data, however, it is believed that these dikes are of Post-Carboniferous age. Von Richthofen mentions porphyries intruded into Carboniferous strata at Pön-si-hu,* and states that the basalts in various parts of the province of Shöng-king appear to be considerably younger than the porphyries.†

Since the epoch of volcanic activity, the region has been denuded to such an extent that all superficial effusive rocks and the original topographic features produced by vulcanism have been entirely obliterated. It is therefore clear that the eruptions occurred not later than the Tertiary period, and not improbably in the Mesozoic.

* China, vol. II, pp. 103, 111. † Ibid., p. 111.


122°
Siung-yüe-chöng
granite
dolerite dike
marble
porphyry
marble in porphyry
soft schists
30° marble
conglomerate
25° quartzite
Li-kuan-ts'un
porphyry
sandstone
40°
40°
porphyry dikes in sandstone
porphyry dikes
sandstone
Wang-kia-ling
Yung-li-chöng
sandstone
Ts'au-kia-tién
sandstone
Yen-kia-tién
conglomerate in sandstone
sandy flat
Wa-fang-k'ou
sandstone
sandstone
dolerite dike
brown grit
overthrust
green limestone
shales
Fu-chou
sandy flat
sandy flat
white quartzite over shale
Ir-shï-li-p'u
sandy flat
olive earthy limestone
alluvial flat
Ma-tién-tzï
Wa-fang-tién
olive sandstone
purple and green shale
green shale
green shale
olive sandstone
olive limestone
Wu-kia-tién
Huang-kia-chuang
overthrust
purple shales
gray quartzite
gneiss
Ting-t'un
sandy flat
San-kua-miau
Soil of green shale and buff limestone
Pu-lan-tién
L. L. POATES, ENGR'G CO., N.Y.
122°
10 5 0 10 Miles
10 5 0 10 20 Kilometers

LIAU-TUNG.

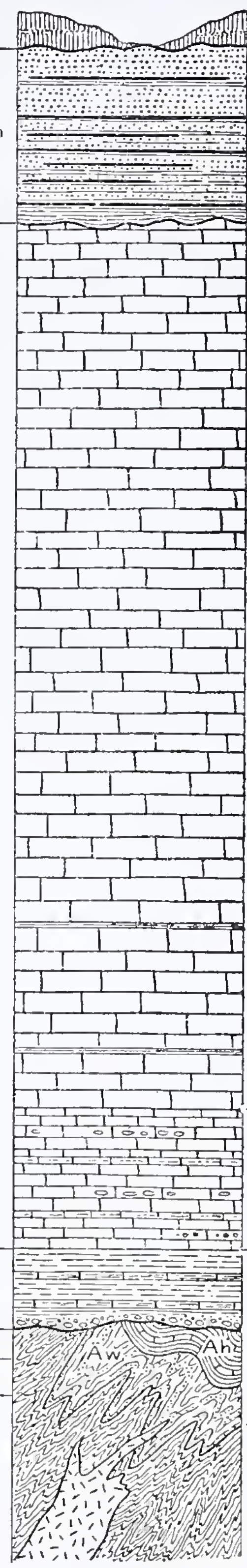
SECTION II

NORTHWESTERN CHINA

PROVINCES OF

CHÏ-LI AND SHAN-SI

			Feet.	Meters.	
Quaternary.	Huang-t'u formation.		0–230+	0–70+	Loess with beds of gravel and sand.
	—Unconformity.—				
Upper Carboniferous.	Shan-si formation.	Csh	700+	210+	Sandstone and shale with numerous thin coal seams; rocks mostly buff, green, brown, or black.
	—Unconformity.—				
Cambro-Ordovician.	Ki-chóu formation.	€Ok	2,500+	760+	Uniform dark limestone in massive beds, rarely associated with gray shales.
			400±	120±	Gray limestone in part shaly. Locally conglomeratic and oolitic.
	Man-t'o shale.	€m	180 to 350	55 to 110	Red shales with impure limestone and conglomerate.
Algonkian.	Unconformity.				
	Hu-t'o series.	Ah			Gray slates and limestones.
	Wu-t'ai series.	Aw			Schists, quartzites, and marble.
Archean.	T'ai-shan complex.	ARt			Gneiss, schists, and granite.



Total thickness of Paleozoic strata . . 3,550 to 3,950 | 1,020 to 1,130

FIG. 16.—GENERALIZED SECTION OF ROCKS OF WU-T'AI DISTRICT, SHAN-SI.

CHAPTER VI.

STRATIGRAPHY OF WESTERN CHÏ-LI AND CENTRAL SHAN-SI.

By Bailey Willis and Eliot Blackwelder.

The stratigraphy of western Chï-li and central Shan-si is similar in many respects to that already described for Shan-tung. It is, however, less well known to us in detail, because in the former province we made rather minute surveys of small districts, whereas in Chï-li and Shan-si we moved more rapidly and were obliged to leave many things of greater or less importance unstudied; and furthermore, the rocks that we saw included certain Pre-Cambrian terranes, which present obscure relations beyond the reach of any but the most careful investigation.

In this region we were able to distinguish all of the larger divisions of the geologic column found in Shang-tung, with the addition of at least two distinct systems belonging to the Pre-Cambrian. The general sequence of formations is given in Fig. 16, and in more detail, especially with reference to the Pre-Cambrian, in the statement of classification on page 100.

PRE-CAMBRIAN.

The time preceding the Cambrian period is represented here by at least three distinct systems of rocks, comparable in magnitude with divisions of the Pre-Cambrian in the United States. The two older ones are greatly metamorphosed, while the youngest is much less altered. The oldest system is the T'ai-shan complex, consisting of various profoundly metamorphic rocks, which we consider Archean, but which are intimately associated with granites and other igneous intrusives, many of which are less metamorphosed and are presumably Algonkian. The second system, the Wu-t'ai schists, is plainly of sedimentary origin, but has been strongly metamorphosed. The third, the Hu-t'o system, is composed of slighty altered limestones and slates.

T'AI-SHAN COMPLEX.

The rocks of the T'ai-shan complex are broadly exposed in the vicinity of T'ang-hién and Fóu-p'ing-hién, Chï-li, and along the divide between that province and Shan-si. They occur also in the dissected upland west and

south of the city of Hin-chóu, in the base of the Ki-chóu-shan southeast of that city, and more extensively along the northern base of the Wu-t'ai range. The complex probably appears in other localities where it is difficult to distinguish it from other metamorphic rocks of later age. On these rocks our most extensive observations were made between T'ang-hién and Fóu-p'ing-hién, Chï-li, where the complex is distinct from all the younger formations.

Classification of the Rocks of Chï-li and Shan-si.

Formation.	Character.	Period.
River gravels and sands.	Generally coarse deposits, mostly of sand.	Pleistocene and Recent.
Huang-t'u formation.	Chiefly loess, with notable amounts of sand and gravel.	
Dikes.	Quartz-porphyries.	Post-Paleozoic.
Shan-si formation.	Sandstone and shale, with numerous coal beds.	Carboniferous.
		Unconformity.
Ki-chóu limestone.	Gray to brown massive and thin-bedded limestone.	Cambro-Ordovician. (*Sinian system.*)
Man-t'o shale.	Red shale and sandstone, with local basal conglomerate.	
		Unconformity.
Ta-yang limestone.	Gray siliceous limestone, with abundant chert.	Neo-Algonkian. (*Hu-t'o system.*) Note: The Ta-yang limestone is probably equivalent to the Tung-yü and Tóu-ts'un.
Tung-yü limestone.	Gray siliceous limestone, interbedded with gray to purple slates.	
Tóu-ts'un slate.	Gray to purple slate, with beds of limestone, quartzite, and conglomerate.	
		Unconformity.
Si-t'ai schists.	(Chloritic and allied schists, with coarse conglomerate of quartzite and granite pebbles.)	Eo-Algonkian. (*Wu-t'ai system.*) Note: The stratigraphic relations of these divisions are not positively determined.
Nan-t'ai schists.	(Marble, quartzite, and jasper with chlorite- and biotite-schists.)	
Shï-tsui schists.	(Arkose, quartzites, complex mica-schists, and amphibolites.)	
		Unconformity.
Augen-gneiss.	Quartz, feldspar, and biotite, constituting a massive uniform rock, probably intrusive.	Unclassified Pre-Cambrian.
Peï-t'ai gneiss.	Quartz, feldspar, muscovite, and chlorite; possibly of sedimentary origin, and if so, the youngest member of the Wu-t'ai system.	
Metamorphosed intrusives.	Granite, biotite- and hornblende-schists.	
T'ai-shan complex.	Gneisses of heterogeneous composition and intricate structure, forming a basal complex.	Archean.

T'AI-SHAN COMPLEX IN WESTERN CHÏ-LI.

Gneisses near T'ang-hién.—The basal complex seen near T'ang-hién is composed of gneisses and schists with abundant igneous dikes, some of which are more or less metamorphosed. It closely resembles the T'ai-shan complex of Shan-tung, but it contains certain rocks of sedimentary origin not seen in this association elsewhere.

The prevailing gneiss is a brown quartzose rock in which the dark mineral is either hornblende or biotite. Although the texture varies through thick beds, the rock is usually fine-grained in detail; the structures called "augen" are only locally developed. A distinguishing feature of these gneisses is the inclusion of numerous lenticular masses of dark amphibole-schist and biotite-schist, varying in size from a few inches to many feet in length, but usually of moderate dimensions.

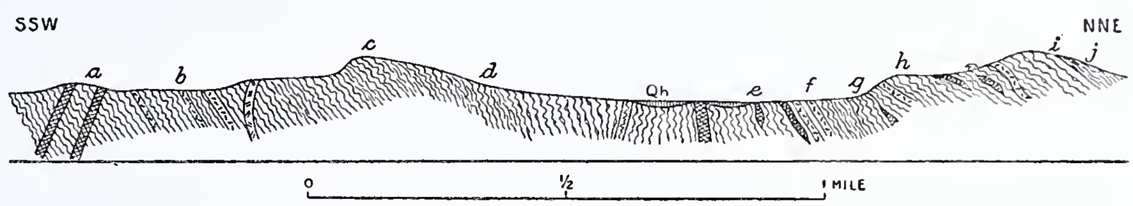


FIG. 17 (Blackwelder).—T'ang-hién, Chï-li. T'ai-shan complex (Archean). Detail of metamorphic succession showing variety of gneisses and schists with both altered and unaltered intrusives. $a =$ gray gneiss cut by greenstone dikes; $b =$ gray granite porphyry-dikes; $c =$ gray biotite-gneiss and schist; $d =$ light gray augen-gneiss; $e =$ lenses of amphibolite in gneiss; $f =$ gray granite-porphyry dikes; $g =$ white sericite-schist; $h =$ brown hornblende-gneiss with amphibolite lenses; $i =$ gray augen-gneiss; $j =$ biotite-schist.

In megascopic character the gneiss is notably variable (Fig. 17). On the one hand, it approaches an unaltered granite so closely that the term "gneissoid granite" is most appropriate; such is a biotite-granite exposed along the border of the hills northwest of Wan-hién. On the other hand, the gneiss grades off into mica-schists. In many places the parallel injection of acid igneous material in thin laminæ has given the rock a conspicuously banded appearance; and the subsequent folding of the mass has resulted in contorted banding.

On the northern slope of the mountain, about 3 miles northeast of T'ang-hién, the gneiss contains biotite- and muscovite-schists with which is associated a small mass of coarse white marble. The marble contains streaks of muscovite and is in contact with whitish muscovite-schists, which are probably sedimentary in origin. There is also in the vicinity a highly quartzose gneiss, containing very little feldspar and only thin streaks of biotite; it is thought that this may have been an ancient quartzite in which the grains of sand and mud have recrystallized. In the same region occur sericite-schists, amphibolites, and other rocks, which

suggest a sedimentary origin. The advanced condition of metamorphism in the whole complex made it impracticable in a brief survey to ascertain whether the prevailing gneiss was formerly a granite intruded into older sediments, or was an ancient gneiss on which were deposited the sediments that finally became schists and marble, or is itself a portion of a sedimentary series.

Gneisses along the Sha-ho.—The gneissic rocks exposed along the Sha-ho and its numerous tributaries, from the village of Wang-k'uai-chön west to the Great Wall, are in general similar to those near T'ang-hién. In texture and mineral constitution the prevailing gneiss is the same, and it likewise includes the lenses of amphibolite and parallel sheets of acid granitic material, such as we have already described with reference to the rocks of the T'ang-hién district.

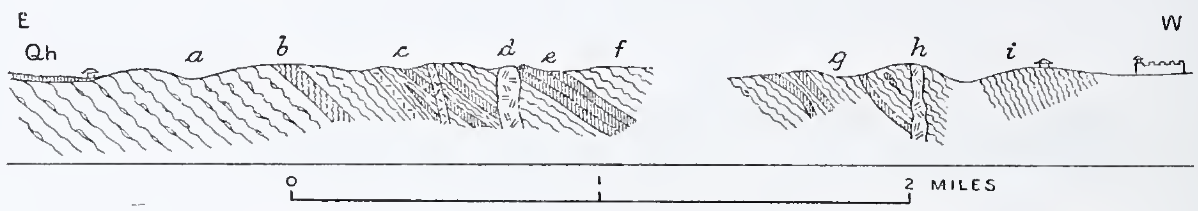


FIG. 18 (Blackwelder).—Fóu-p'ing-hién, Chï-li. Detail of T'ai-shan complex showing variations in the gneissic rocks. a = coarse gray augen-gneiss; b = hornblende-gneiss; c = dikes of granite-porphyry in banded gneisses; d = brown granite-porphyry; e = hornblende-schist; f = gray biotite-gneiss; g = alternate hornblende- and mica-gneisses; h = granite-porphyry; i = fine-grained biotite-gneiss.

Intrusives in the ancient gneisses.—Although obviously younger than the gneisses and schists, the numerous igneous rocks intruded into the complex are not easily dissociated from it (Fig. 19). They group themselves roughly as granites, aplites, granite-porphyries, feldspar-porphyries, and altered basic rocks classed as greenstones.

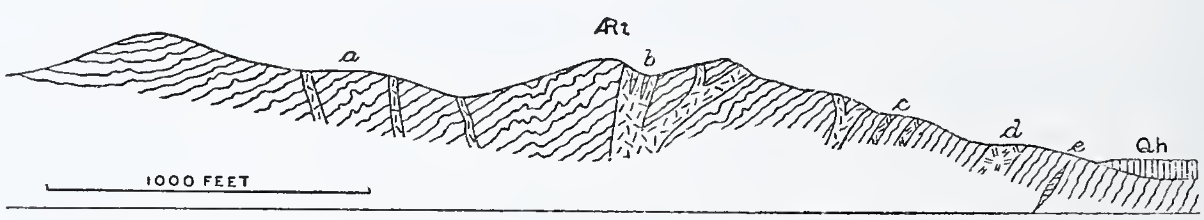


FIG. 19 (Blackwelder).—T'ang-hién, Chï-li. Detail of T'ai-shan complex (Archean), showing massive gneiss cut by a variety of dikes of different ages. a = brownish hornblende-gneisses cut by aplite dikes; b = gray granite-porphyry dikes; c = hornblende-porphyry sheets; d = schistose greenstone; e = amphibolite.

Gray biotitic granite-porphyry occurs in dikes 2 to 15 feet, 0.6 to 4.5 meters, in breadth in the mountains near T'ang-hién; it is often distinctly bluish on fresh surfaces, a handsome rock which the Chinese utilize largely in the manufacture of mill-stones. Several miles north of Ning-shan, a black and white hornblende-granite of coarse texture was found in the float, but the main body was not observed and no other occurrences were

A

B

A. Divide between provinces of Chï-li and Shan-si, 5 miles south of Lung-ts'uan-kuan, looking north, atlas sheet D I, elevation 6,000 feet; showing surface eroded on gneisses of the T'ai-shan complex, and bedded character of ancient crystalline rocks.

B. Near Si-ta-yang, Chï-li, atlas sheet F I. View of bluffs of Pre-Cambrian Ta-yang limestone along the T'ang-ho.

noted. Farther to the west, in the region about Fóu-p'ing-hién, there are, in addition to the gray varieties, granite-porphyries of a decidedly pinkish tinge. These also occur in dikes 3 to 10 feet, 1 to 3 meters, in thickness.

The aplites are dense gray-white rocks, which occur in thin sheets and dikes. They are evidently associated genetically with the granite-porphyries, for in one instance a thin aplite sheet was traced into a larger dike of the blue-gray holocrystalline rock, and was thus proved to be an apophysis of the latter. Some of the aplites are flecked with minute blotches of epidote and garnet.

The feldspar-porphyries are light brown, often reddish, rocks, which contain stout phenocrysts of feldspar, and near Fóu-p'ing-hién the dikes usually exhibit quartz crystals also.

Dioritic rocks, hornblende-porphyries, and greenstones in considerable variety are frequent in the region from T'ang-hién to Fóu-p'ing-hién, occurring as dikes and sheets of rather large dimensions wherever the basal complex is exposed. One dike of greenstone (dioritic?) in the southeast end of the mountain west of Wan-hién has a maximum breadth of 400 feet, 120 meters. The schistose greenstones appeared first just west of Fóu-p'ing-hién and became more abundant as we approached Wu-t'ai-shan. Dikes 100 feet, 30 meters, thick are frequent.

The intrusives mentioned in the last paragraphs do not show equally the effects of metamorphism, and probably are not all of the same age. The feldspar-porphyries along the Sha-ho appear to have suffered no metamorphism other than weathering. They are plainly subsequent to the last episode of severe deformation, and are probably of Post-Sinian age. Among the porphyries and aplites near T'ang-hién the effects of mashing and partial recrystallization are obvious under the microscope, but are not revealed megascopically. They are distinctly more deformed, however, than the feldspar-porphyries just described. Of the greenstones and basic porphyritic rocks, some are notably metamorphosed, while others appear to have undergone little change. Many of the greenstones are plainly schistose amphibolites, but their origin from basaltic intrusives is, nevertheless, scarcely questionable.

The complex is everywhere crossed by veins of pegmatite and quartz, which are in large part earlier than most of the smaller igneous intrusions. It is probable that most of the pegmatites are genetically akin to the granites, although we have no definite data on this point. In addition to the commoner pegmatites, which consist of coarse crystals of quartz and orthoclase, it is not uncommon to find others in which hornblende or biotite are prominent constituents; most of the hornblende pegmatites occur west of Fóu-p'ing-hién.

T'ai-Shan Complex in Northern Shan-si.

Granites in the Hin-chóu district.—The prevailing rock of the complex in the Hin-chóu basin is a coarse-grained reddish granite, which contains orthoclase, biotite, and blue-gray quartz. This is the only rock which appeared in the basal system where it is exposed in the slopes southeast of Han-yang. Five to 10 miles, 8 to 16 kilometers, northeastward, in the base of the same mountain, the red granites are associated in an unknown relation with schistose greenstones, ancient dioritic rocks, and more recent brown feldspar-porphyries.

Southwest of the city the red granite appears in company with dark biotite-schists and a highly acid gray granite of fine texture. Being harder than the other components of the mass, the gray granite is the last to be reduced during erosion, and forms the low monadnocks visible in the vicinity of the city.

Both the red and the gray granites are massive rocks not conspicuously gneissoid or schistose. Like the granites of the T'ai-shan complex of Shan-tung, they have probably been intruded into the mica-schists with which they are in some sections associated, and are probably of Algonkian age.

Gneisses in the Wu-t'ai district.—The Wu-t'ai-shan consists chiefly of metamorphic rocks of sedimentary origin, which we assign to the Wu-t'ai system of the Eo-Algonkian, but the T'ai-shan complex is represented by gneisses, which flank the range on both sides.

The basal T'ai-shan complex, which is so wide-spread about Fóu-p'ing-hién, Chï-li, was followed up the Sha-ho and found to form the larger part of the mountains along which stretches the South Branch of the Great Wall. The rock is for the most part a firm biotite-gneiss, frequently reddish in color, though often gray, and it grades insensibly into gray mica-schists. From the intimate association of the schists and gneisses, it is inferred that the two are portions of a single mass of variable composition, in which the effects of metamorphism have been correspondingly unlike. The upper limit of the T'ai-shan in this section is the unconformity with the Shï-tsui group of the Wu-t'ai system. The contact, which we take to be the unconformity or a plane of bedding near it, was seen at two points in the hills southeast of Shï-tsui, but was not traced further. In a general line, however, it extends northeast and southwest along the southeastern side of the Wu-t'ai mass.

The T'ai-shan complex is likewise represented in a wide area traversed by the Hu-t'o-ho, northwest of the Wu-t'ai-shan. Von Richthofen, crossing the range in 1871, found the northern foothills composed of reddish mica-gneiss.* This he considered to be the same as the basal gneiss,

*Von Richthofen, China, vol. II, page 364.

which he had already seen in many other parts of China. Willis, en route from Tai-chóu to Chang-hién-pu, also found gneiss 3 miles, 5 kilometers, south of the base of the northern slope. It is a granitoid gneiss cut by large dikes of schistose greenstone, and is followed by quartzite and schists of the Wu-t'ai system.

Another small area of gneiss, which may possibly be part of the T'ai-shan complex, or may be much younger, is exposed in the higher portion of the Wu-t'ai range, on the summit and upper slope of Peï-t'ai.

Correlation.

In the provinces of Shan-si, Chï-li, and Shan-tung the oldest metamorphic complex presents almost identical development, and we believe that we have to deal with the same basal system in the several areas. The rocks appear to be largely of igneous origin, though in part sedimentary, and contain abundant acid and basic intrusions belonging to many generations of igneous activity. They are characterized by exceedingly complex structure and advanced metamorphism. The stratigraphic position is everywhere basal, the complex underlying Paleozoic or Algonkian sediments and being itself bottomless. Such is the identity of constitution and stratigraphic position throughout northern China that the name T'ai-shan, applied to the system in the type locality in Shan-tung, is extended to the other masses which we observed in Chï-li and Shan-si.

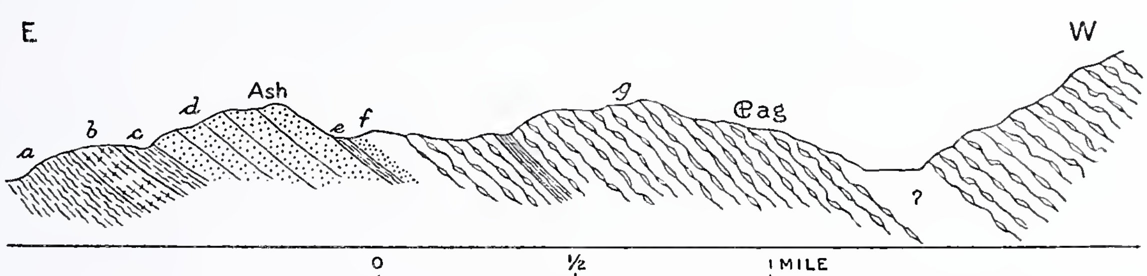


Fig. 20 (Blackwelder).—4 miles, 6 kilometers, south of Shï-tsui, Shan-si. Augen-gneiss in contact with lower members of the Shï-tsui series. *a* = biotite and chlorite-schists; *b* = mottled green and pink amphibolite; *c* = white sericite-schist; *d* = brownish arkose quartzite; *e* = biotite-schist; *f* = brown micaceous quartzite; *g* = massive gray augen-gneiss.

The characters of the T'ai-shan complex are so distinctive and so fundamental that we feel justified in correlating it with the similar systems of America and Europe, as the Archean; but we also recognize that the masses to which the name is applied in this report and accompanying maps include granites and other intrusives of Algonkian and later eras.

UNCLASSIFIED PRE-CAMBRIAN.

Augen-gneiss.—Along the T'ai-shan-ho, 4 to 7 miles, 6 to 11 kilometers, above Shï-tsui (Plate XVIII), and again about 4 miles, 6 kilometers, below that village (Fig. 20), we found a gneiss which is different from any seen

in the basal complex. In the first occurrence noted the gneiss is in contact with the magnetic quartzite of the Shï-tsui group, while in the latter it lies adjacent to the arkose quartzite, which appears to be one of the lowest members of the sedimentary sequence. In both cases the banding of the gneiss is parallel to that in the schistose sedimentaries, as if gneiss, schists, and quartzites were all in parallel stratigraphic sequence. It is more probable, however, that the banding of the rocks is parallel because it has been produced simultaneously by forces which affected both gneiss and sedimentaries.

The rock consists almost entirely of medium-grained augen-gneiss in which the colors range from deep purplish-gray through pinkish-gray to black-and-white. The mineral constituents observable in the hand specimens are mainly quartz, white and pink feldspars, and lustrous sepia-colored biotite. The texture of the rock is unusually even, and varies but slightly from point to point. The so-called "augen" are lenses of quartz and feldspar, averaging 1 centimeter in length, with a breadth of about half as much. In marked contrast to the T'ai-shan gneisses, this rock is very homogeneous; there is little variation in its character in the section on the T'ai-shan-ho, which is continuous for 3 miles, 5 kilometers. Veins of quartz and pegmatite and also igneous dikes are comparatively rare. Most of the last are evidently intrusions of more recent date than the metamorphism; in addition the gneiss contains a few thin bodies of serpentine and greenstone schists, which appear to be ancient intrusives now thoroughly metamorphosed.

This homogeneity of composition, and the broad extent of the mass exposed, incline us to the hypothesis that the augen-gneiss is a metamorphosed intrusive granitic rock,—perhaps a porphyritic granite. That we did not find dikes or other offshoots from the gneiss penetrating the strata at the contacts with the quartzite-bearing series, at several different localities, may be due to later metamorphism which has obscured the contact phenomena. The contacts appeared to be sharp and clean; they probably represent planes of shearing.

The idea that the gneiss may be a portion of the T'ai-shan complex, lying beneath the Wu-t'ai schists in an overturned anticline, is rendered doubtful by the fact that the quartzites which bound it on the south are not repeated on its northern edge. An overthrust on each side of the gneiss would explain the relations, but the structure is regarded as less probable than that of intrusion.

Peï-t'ai gneiss.—Another gneiss of undetermined relationships forms the summit and upper slopes of Peï-t'ai-shan, the highest peak of the region.

At the surface the rock is a mottled greenish and brownish granitoid gneiss, composed of quartz and feldspar with muscovite and chlorite. Most of the rock has suffered recrystallization during metamorphism, and the micas are apparently not the original femic* minerals. Furthermore, the rock of which a specimen was obtained was weathered and difficult to determine. The Peï-t'ai gneiss is surrounded on the south and east by green chlorite-schists of the Si-t'ai group of the Algonkian Wu-t'ai system. Between the exposures of the typical gneiss on the one hand and the green schists on the other, there is an ill-defined belt of gray muscovite-schist, which appears to grade into the adjacent gneiss on the one side and into the schist on the other. The gentle slopes of the peak, however, are covered with soil through which only scattered outcrops of rock appear. The relation between gneiss and chlorite-schist was not, therefore, closely observed.

We can not correlate the Peï-t'ai gneiss definitely. It may belong to the T'ai-shan complex or the Wu-t'ai system, or be intruded in the latter. If the Peï-t'ai gneiss belongs to the T'ai-shan complex, it underlies the Si-t'ai group and may appear in its present position, either on the axis of an anticline or above an overthrust fault. We at first entertained the view that the larger structure of the Wu-t'ai range was anticlinal, and that the Peï-t'ai gneiss was of the T'ai-shan complex, but more thorough study of our notes and specimens indicates that the structure is that of a closed syncline, or of a monocline in which the strata are repeated by overthrust.

If the Peï-t'ai gneiss is a member of the Wu-t'ai system, it probably overlies the Si-t'ai group and occurs as the highest stratum in a syncline. The fold may be limited on the northwest by an overthrust. The constitution of the gneiss is consistent with a sedimentary origin, since it is probable that the conditions which have converted the uniform shale of the Si-t'ai group into chlorite-schist would change an arkose or graywacke into such a gneiss as the Peï-t'ai. The presence of much calcite and of muscovite and chlorite, rather than hornblende or biotite, is suggestive. The assignment of the Peï-t'ai gneiss to the Wu-t'ai system, and to the superior position in that system, is thus qualified only by our lack of definite knowledge of the structure of the range.

Equal consideration should be given to the possibility that the Peï-tai is intruded into the Wu-t'ai schists. The petrographic evidence does not exclude an igneous origin, and the apparently rounded mass is not unlike that of a batholite. The encircling belt of muscovite-schist may represent the zone of contact metamorphism with the Wu-t'ai rocks.

* For use of this term to designate the ferromagnesian constituents of rocks see "Quantitative Classification of Igneous Rocks" by Cross, Iddings, Pirsson, and Washington.

PRE-WU-T'AI UNCONFORMITY.

Although the relation of the T'ai-shan complex to the Wu-t'ai system has not been definitely observed in any locality, there is no doubt that the two are unconformable. The dissimilarity of the two systems is incompatible with any other relation; the T'ai-shan complex is apparently largely igneous and is profoundly metamorphosed like the Archean, while the Wu-t'ai strata are very largely of sedimentary origin and are rather less altered. The latter also contain arkose, probably derived from the T'ai-shan.

The unconformity between the two systems may be exposed at two points along our route, to which we have already referred. One is south of Tai-chóu, on the northern slope of the Wu-t'ai range; the other is southeast of Shï-tsui.

South of Tai-chóu, Willis observed that granitoid gneiss is followed by quartzite and schist. For $3\frac{1}{2}$ miles, 6.5 kilometers, from the mountains, south of the plain of the Hu-t'o-ho, the gneiss forms a belt through which a deep canyon is cut. At its head the canyon widens to a gravel-floored valley with slopes of quartzite-schist and mica-schist, which appear to dip north about 80° toward the closely adjacent gneiss. Near the contact, for a width of several hundred feet, the schists are much decomposed and iron-stained. The actual contact was not found. It is probably one of unconformable deposition, which is overturned; but it may also be an overthrust.

Southeast of Shï-tsui the unconformity between the Wu-t'ai system and the T'ai-shan complex is exposed in a continuous section, but the basal layers are so thoroughly schistose that the location of the actual contact was not determined. The lowest recognized sedimentary member is a coarse-grained feldspathic quartzite (stratum 3, Plate XVIII), which is separated from the typical T'ai-shan gneiss by soft gray mica-schists, which either might have been produced by extreme metamorphism of shaly sediments beneath the quartzite, or be part of the gneissic complex.

The mineral composition of the quartzite is such that it probably represents an arkose sandstone, which has since been severely deformed and partially recrystallized. The original feldspar fragments, which were worn and more or less decayed, have been extensively granulated, and from the product fresh feldspars have developed. The rocks of the T'ai-shan complex, constituting the mountains toward the east, are such as may have yielded arkose sediment under appropriate conditions of weathering. The contact thus resembles that of a basal conglomerate resting unconformably upon an older series.

WU-T'AI SYSTEM.

Definition of the Wu-t'ai system.—Von Richthofen, in 1871, found the Wu-t'ai-shan and its foothills composed largely of greenish chlorite-schists, and certain other metamorphic rocks which were difficult to separate stratigraphically from each other. He concluded that they were later in age than the red gneiss and granite, and older than the Sinian. In his provisional table for the correlation of the general sections in various parts of China,* he expresses the opinion that the Wu-t'ai schists probably represent the lower portion of the Huronian system in the United States, a correlation based, no doubt, on lithologic character. To the whole group he applied the name "Wu-t'ai Schichten," which we retain by using the phrase "Wu-t'ai system." Along the route traveled by von Richthofen, however, only a small part of the metamorphic rocks of the Wu-t'ai district are visible. Coming into the region from the southeast, we crossed other metamorphic formations which he did not see, and, as they are related by their general characteristics to the Wu-t'ai schists, we have enlarged the term so as to include them. When the district comes to be studied in detail throughout, additional formations may be discovered, which do not appear along either of the routes thus far explored.

The Wu-t'ai schists occur in the Wu-t'ai range for an undetermined distance east and west of the summit peaks, southward nearly to the villages of Tóu-ts'un and Liu-yüan, and for several miles south of the T'ai-shan-ho near Shï-tsui. They were not seen in Chï-li nor elsewhere in Shan-si.

The facts observed in our brief surveys of this intricate system suffice only to yield suggestions of stratigraphy and of structure. The sequence of formation and the correlation of separate sections are therefore inferred rather than established. The observed sections are described in the following paragraphs, and the inferred correlations are stated under a distinct head.

Descriptions of Observed Sections.

Shï-tsui section (Strata 1 to 20, Plate XVIII).—The rocks of the Shï-tsui section are exposed along the T'ai-shan-ho, from a point 1½ miles, 2.5 kilometers, southeast of Shï-tsui to a point 3¼ miles, 5.25 kilometers, north of there (see Plate XVIII). In the southern portion of the section are feldspathic quartzites associated with dark mica-schists and purer quartzite; in the middle are mica-schists and fine-grained gneisses with certain other rocks; and the northern end consists of magnetic quartzite and jaspillite.

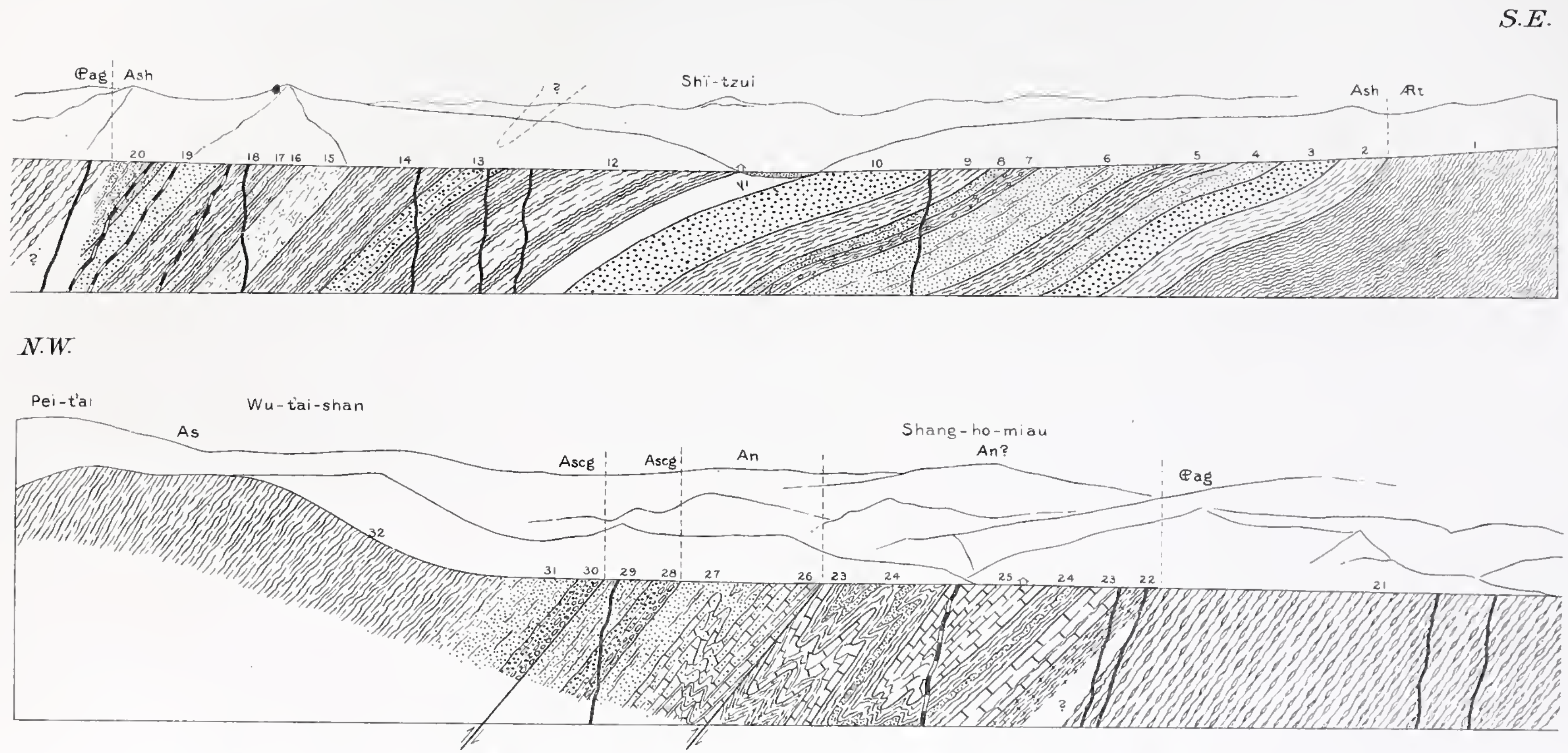
*Von Richthofen, China, vol. II, page 378.

In describing the different members of this group, we shall begin at the southeast end of the section, which is probably the base. The supposed basal member has already been mentioned in connection with the Pre-Wu-t'ai unconformity. This is a pale grayish or pinkish quartzite (stratum 3) which is spotted with crystals of red orthoclase often several millimeters in breadth. As mica is sometimes present, though in relatively small amounts, hand specimens might be mistaken for quartzose granite, but in large masses the stratification is obvious. The microscope reveals the fact that the original arkose has been completely cemented and severely deformed, the original grains having been partly demolished and recrystallized.

The feldspathic quartzite was again observed along the eastern tributary of the T-ai-shan-ho, 4 miles, 6.5 kilometers, south of Shï-tsui (Fig. 20). There it lies adjacent to an augen-gneiss identical with that which interrupts the succession in the T'ai-shan-ho section. The quartzite lies upon layers of dark biotite-schist, which are interbedded with a stratum of pink-and-green amphibolite composed of actinolite and calcite—probably an altered limestone. This is associated with white sericite-schist. The sedimentary origin of these schists can hardly be questioned. It is therefore probable that at this point the feldspathic quartzite is not the lowest member of the stratified series, although it is undoubtedly near the base.

In the section east of Shï-tsui the feldspathic quartzite grades upward into a pink quartzite containing mica, but not much feldspar. Toward the top thin layers of mica-schist are interbedded, and by a gradual transition the rock comes to be largely a mica-schist including layers of pink quartzite. The schist is a massive rock, which cleaves with considerable difficulty and weathers like a hard argillite. The cleavage planes are sprinkled with purplish-brown biotite, which is frequently aggregated into flat disks 1 or 2 centimeters in breadth. Some of the layers are rich in red garnets while others contain scapolite and staurolite. Following these mica-schists and forming the south slope of the canyon at Shï-tsui, occur brown-banded quartzites which are nearly uniform in character. The sequence up to this point includes about 3,000 feet, 900 meters, of strata, forming beds numbered 3 to 10. The river bed makes a gap of several hundred feet in our section. The concealed rocks are probably soft mica-schists.

On the north side the quartzites are absent, and to the northwest we crossed for 3 miles, 5 kilometers, a succession of gray mica-schists and fine-grained mica-gneisses. The schists are at first biotitic, but muscovite becomes a prominent constituent near the northern end of the section. Thin beds of chlorite-schist occur not infrequently throughout the section. About $2\frac{3}{4}$ miles, 4.4 kilometers, above Shï-tsui, the schists contain a rather



Geological section of the Wu-t'ai (Algonkian) system, observed on the T'ai-shan-ho, extending from southeast to northwest across the southeastern slope of the Wu-t'ai-shan.

LEGEND

SHOWING THE SUCCESSION OF METAMORPHOSED SEDIMENTARY ROCKS OF THE WU-T'AI SYSTEM, AND THE INTRUSIVES ASSOCIATED WITH THEM. (THE MINOR DETAILS OF THE FOLDING ON THE LEFT SIDE OF THE SECTION ARE DIAGRAMMATIC). 1, FINE-GRAINED BIOTITE-GNEISS (Ꞓt); 2, BIOTITE SCHIST; 3, PINK ARKOSE QUARTZITE (Ash); 4, DENSE GRAY MICACEOUS QUARTZITE; 5, FINE-GRAINED BIOTITE-SCHIST; 6, MICACEOUS QUARTZITE; 7, BIOTITE-SCHIST, (CERTAIN LAYERS CONTAIN GARNET AND OTHERS SCAPOLITE); 8, MICACEOUS QUARTZITE; 9, DARK BIOTITE-SCHIST; 10, MASSIVE BROWN QUARTZITE; 11, CONCEALED BY ALLUVIUM; 12, ALTERNATION OF GRAY MICA-SCHIST AND GNEISS WITH THIN CHLORITE-SCHIST; 13, ARKOSE-SCHIST WITH PINK FELDSPARS; 14, MUSCOVITE-SCHISTS AND GNEISSES: 15, MASSIVE SPOTTED GREENISH AMPHIBOLITE; 16, MICA-SCHIST; 17, AMPHIBOLITE; 18, MICA-SCHIST AND GNEISS; 19, HARD MAGNETITE-QUARTZITE; 20, MODERATELY SCHISTOSE PINK QUARTZITES WITH SEAMS OF MICA-SCHIST; 21, MASSIVE GRAY AUGEN-GNEISS; 22, BIOTITE SCHIST WITH GARNETS; 23, WHITE MARBLE WITH THIN LAYERS OF GARNET-SCHIST; 24, ALTERNATE CHLORITE AND BIOTITE-SCHISTS WITH SCHISTOSE BROWN QUARTZITE; 25, PURE WHITE MARBLE; 26, BANDED DARK SILICEOUS MARBLE WITH THIN LAYERS OF SLATE AND LOCAL BEDS OF HEMATITE NEAR THE OVER-THRUST; 27, DARK BANDED QUARTZITE SLIGHTLY SCHISTOSE; 28, GREEN SCHISTOSE CONGLOMERATE FOLLOWED BY ARKOSE SCHIST; 29, GRAY QUARTZ-MICA-SCHIST; 30, GREEN SCHISTOSE CONGLOMERATE FOLLOWED BY ARKOSE-SCHIST; 31, GRAY QUARTZ-MICA-SCHIST; 32, UNIFORM GREEN CHLORITE-SCHIST EXTENDING NORTHWEST TO THE SUMMIT OF THE RANGE.

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thick mass of amphibolite (stratum 15), in which the large hornblende crystals form a matted network, embedded in the light grayish matrix of the rock.

The sequence, as exposed in the section along the T'ai-shan-ho, is completed by about 1,300 feet, 400 meters, of schists and quartzites (strata 19 and 20). At the base, following the mica-schists in apparent conformity, we found nearly 600 feet, 185 meters, of steel-gray quartzite. The rock is locally so rich in magnetite as to be almost black, and it disturbs the compass needle at a considerable distance from the outcrop. Banded jaspilites and red jasper occur in thin bands, interstratified with the quartzite. This member grades upward into a pink micaceous quartzite, which is usually massive, but sometimes schistose. Thin strata and partings of green schists are frequent.

The structure of this sequence of strata is apparently that of a simple monocline dipping from 30° to 70° northward; but the gentler dips being near the southern end of the section and the steeper ones at the northern end, there is a divergence of the strata upward which suggests a syncline that is closed and overturned southward. The southern and northern ends of the section are similar in that both are decidedly quartzose and contain biotite-schists. The black magnetite-quartzite (No. 19) may represent the ferruginous quartzite (No. 10), the iron peroxides being reduced to magnetite by the influence of the intrusive granite, from which we suppose the adjacent augen-gneiss (No. 21) to have been derived. The schists and quartzites (No. 20) would then correspond to the similar strata on the gently inclined southern limb (No. 5 to No. 9), and the lowermost members of the group, which are not present on the northern margin, would be cut out by the intrusive granite.

Thus we may reasonably regard the Shï-tsui section as representing a body of sediments, partly duplicated in a synclinal fold and cut off by the intrusion of the granite, which now forms the augen-gneiss, that extends 3 miles, 5 kilometers, upstream to Shang-ho-miau.

Shang-ho-miau section (Strata 22 to 24, Plate XVIII).—In this section there is an alternation of marble, quartzites, and various kinds of schists, all of which are metamorphosed sediments. The best exposures occur near the temple, Shang-ho-miau, in the canyon of the T'ai-shan-ho and its western tributary, from 7 to 9 miles, 11 to 15 kilometers, northwest of Shï-tsui. The strata are steeply inclined and trend southwest in a narrow belt.

Bordering the exposure of the augen-gneiss, on the southeast side of this belt, occurs a mass of garnet-staurolite-schist. This is followed by coarse-grained white marble, which is associated with thinner strata of garnet-schists. The next succeeding member consists of an alternation of

garnet-biotite and chlorite-schists with banded gray and reddish-brown quartzites, even the quartzites being more or less schistose. More marble follows, but this member is much thicker than the first and is not interbedded with schists. The rock is white and medium grained, and certain layers contain bunches of white needle-like crystals, which are probably tremolite. The white marble rests upon quartz-biotite-schist and lies in an overturned syncline, the northern limb of which is cut off by an overthrust, which brings schists and quartzites upon it from the north. The fault is not parallel to the strike of the synclinal beds, but trends more toward the east, and there is, therefore, along the western tributary of the T'ai-shan-ho, a more complete sequence of the underthrust rocks. The white marble is there followed on the north by chloritic and sericitic schists and schistose dark quartzites, which appear to be a recurrence of the strata observed on the southeast side of the marble. The garnet-schist and the thinner member of marble beneath were not observed, however, in this section; they are probably suppressed by minor folds adjacent to the overthrust, as represented in Plate XVIII.

On following this body of marble and garnet schist into the hills northeast of Shang-ho-miau, it is traced to outcrops in a pass $2\frac{1}{2}$ miles, 4 kilometers, from the river, where it is a tremolitic marble, lying under black quartzite-schist, with a strike N. 25° E. and dip 70° NW. The structure of the marble itself is nearly isoclinal, but on the northeastern slope from the pass the black quartzite is repeated under the marble and with a dip of but 50° NW. The repetition and the relations of the two dips indicate a synclinal structure, the eastern continuation of that observed in the Shang-ho-miau section. Underneath the lower outcrop of quartzite comes in an extensive mass of chlorite and hornblende-schist and biotite-gneiss. The contact may be one of faulting or of intrusion.

Beyond the pass is a peak of red quartzite of the Wu-t'ai system, which is separated from the tremolitic marble by an overthrust that may be traced along the little brook which flows southwest from the pass. The fault is there characterized by the presence of brecciated jasper in discordant contact with garnet-schist. The hade of the fault is steep toward the northwest.

Wu-t'ai-shan section (Strata 26 to 32, Plate XVIII).—The strata which are overthrust upon the marble and schist of the Shang-ho-miau section consist largely of dark-banded quartzite and siliceous marble. Just northeast of the T'ai-shan-ho the members lying immediately north of the fault line are impure ferruginous marble and calcareous arkoses, containing bands of jasper and thin streaks of crystalline hematite. Much larger pieces of the hematite were observed in the float farther down the river, and

from this it is inferred that the mineral occurs locally in thicker masses. These ferruginous rocks are overlain by gray phyllites and siliceous marble.

Where the overthrust crosses the western tributary a somewhat similar association of jasper and hematite was noted in the limestone. It is suggested that this represents a secondary concentration of ferruginous material along the fault-plane.

The overlying rocks in this section are hard reddish-brown and gray banded quartzites and siliceous marble. They are frequently more or less schistose and include many thin layers of sericite-phyllite and chlorite-schist, which were originally layers of shale. The quartzites are locally conglomeratic, containing large well-rounded pebbles of quartz and quartzite. The schists become a more important element northward, and the section finally extends into the great mass of chlorite-schist which forms the summit of the range.

In the transition belt between the quartzites and the green schists there is a sequence from south to north consisting of schistose conglomerate and arkose, then a similar schistose conglomerate, arkose, and quartzite. All of the rocks possess a marked parallel structure, some of them being fissile schists, while others are banded gneisses unquestionably of sedimentary origin. The repetition of the conglomerate-schist and the overlying arkose-schist is believed to be due to an overthrust. The succession from conglomerate-schist through arkose to quartzite, and eventually to the chlorite-phyllites is regarded as a passage from coarse mechanical sediments to finer ones, such as is common in sequence upward from a basal conglomerate, and is considered strong evidence of an unconformity at the base of the Si-t'ai or green schist series.

The conglomerate-schists consist of pebbles of white, gray, and red quartzites up to 20 centimeters in diameter, of vein quartz, and occasionally of granite, embedded in a matrix of green chlorite-schist and graywacke-schist. In this particular locality the pebbles have undergone severe deformation, having been crushed and elongated so that they now lie with their axes parallel to the general direction of schistosity. There are similar conglomerates, however, 4 or 5 miles north of Liu-yüan and elsewhere in the district, which have not been so severely strained. There the pebbles are sometimes fractured along planes which lie at an angle of about 45° to the schistosity of the matrix; some of the pebbles are still intact, but when examined in the microscope the quartz grains show the undulatory extinction, which is characteristic of strained crystals.

Between the conglomerate-schists and the green schists lie the transitional quartzose strata. The schistose arkose is a gray quartzite, in which pink feldspars are abundant. In many layers fissility is prominent and

the cleavage surfaces are sericitic. The schistose quartzite associated with the arkose shows all variations, from fissile gray quartzite to finely laminated quartz-sericite-schist with pearly cleavage planes. By increase in the amount of chlorite these quartzose schists pass insensibly into the green schists beyond.

The great mass of the Wu-t'ai-shan consists of chlorite-schists, which exhibit minor variations in mineralogical character, but nevertheless are essentially monotonous in constitution. The surface is, to a great extent, covered with residual soil and to some degree with loess. Under these circumstances the measurement of detailed sections, such as we observed in the canyons of the T'ai-shan-ho and its tributaries, was not attempted in the mass of the range.

We made general observations in the vicinity of the village of Wu-t'ai-shan, along the summit ridge north of it, on Nan-t'ai, in crossing the passes toward Liu-yüan and Yen-t'ou, and in the canyon of the stream which flows past Yen-t'ou, the O-shui-ho.

Von Richthofen considered the green schists the most characteristic rocks of the system, and, so far as our observations extend, a large part of the mass consists of chlorite-schists unassociated with any other rocks. In themselves the schists exhibit several phases which may be distinguished. In some cases they are massive, not well cleaved, and distinctly argillaceous in composition; chlorite is not visible in this variety, although its presence in a finely divided condition is inferred from the color. Elsewhere are slaty schists or phyllites, with lustrous green surfaces covered with chlorite; in fact this variety appears to consist almost entirely of that mineral. In other phases the chlorite is mingled with biotite, and again with quartz, in thoroughly schistose masses of green color.

From these descriptions it is evident that the quartzose rocks of the Wu-t'ai series are metamorphosed sediments. The derivation of the chlorite-schists is not so obvious, but since they appear to grade directly into the schistose quartzites and possess a mineral constitution which could readily have been derived from the metamorphism of clay rocks, it seems reasonably certain that they too were sediments.

Occurrence of conglomerate on Nan-t'ai.—The slopes of Nan-t'ai consist chiefly of the siliceous marbles, jaspers, and quartz-schists of the southern part of the Wu-t'ai section, but the summit is a mass of chlorite-schist overlying a bed of coarse conglomerate, which contains pebbles of quartzite, quartz, and granite. This conglomerate thus corresponds, both in constitution and stratigraphy, with that seen in the main range. It lies at a gentle dip of 30° to the northwest, and appears to be a synclinal remnant of the highest formation remaining in the peak of Nan-t'ai.

Western section of the Wu-t'ai-shan.—The Wu-t'ai range was crossed by Willis in a rapid reconnaissance, between Tai-chóu and Tung-yü, 20 miles, 32 kilometers, southwest of the above-described T'ai-shan-ho section. The northwestern foothills consist of granitoid gneiss, part of the extensive exposure of the basal complex north of the range. Three and one-half miles, 5.5 kilometers, up a canyon from its mouth, mica- and quartzite-schist come in with a vertical dip. The character of the contact with the granite was not observed, but is supposed to be that of deposition. The schists continue for 5 miles, 8 kilometers, to the summit of the range, which is composed of the prevailing chlorite-schist, that in this locality includes the horizon of conglomerate of large quartz and quartzite pebbles. The dip varies from 30° to 90° toward the northwest. Descending the southern slope, the conglomerate schist is found to extend across the valley into the separate range on the south. It is probably repeated by thrusts and folds. In the northern part of this section, between the granitoid gneiss and the summit of the range, the Wu-t'ai schists are folded in a closed and complex syncline. The occurrence of the schist-conglomerate is probably anticlinal in the main divide, and is very possibly overthrust toward the south upon a synclinal mass. Further southeast are heights of quartzite with nearly vertical dip. They were seen only from a distance, from the aggraded valley on the route to Tung-yü, but are supposed to represent the upper members of the Wu-t'ai system. They are in turn succeeded southeastward by strata of argillite, quartzite, and limestone, lying in more open folds, and these are, with confidence, assigned to the Hu-t'o system.

In this section none of the distinctive strata of the Shï-tsui or Nan-t'ai sections were seen. The siliceous strata are not more prominent than those at the base of the Si-t'ai, and the great body of chlorite-schists corresponds with the main part of that section. Conglomerates of quartz and quartzite pebbles up to 20 centimeters in diameter are very characteristic strata which make the identification complete. The absence of the Shï-tsui and Nan-t'ai rocks, which we regard as older and which should appear at the base between the Si-t'ai schists and the T'ai-shan complex, may be explained by overlap of the Si-t'ai or by overthrust of the T'ai-shan. The contact was indeterminate where seen.

Observations southeast of Yau-t'óu (atlas sheet C I).—The Wu-t'ai schists appear to extend along the southeast side of the T'ai-shan-ho valley for many miles, for they were found again in a valley which joins that river 2.5 miles, 4 kilometers, south of the Yau-t'óu coal district. The rocks there exposed consist of dark purplish biotite-schists, associated with thick masses of white quartzite and greenstone dikes. The float which is brought down the valley from the south contains fragments of granite and

gneiss, indicating that the T'ai-shan complex occurs not many miles away. As in the district about Wu-t'ai-shan, the quartzites and schists in this locality are inclined toward the north; they lie unconformably beneath Cambrian shales and limestones, and are completely covered by them on the north (see Fig. 46).

Grouping and Correlation of Wu-t'ai Strata.

Three groups distinguished.—An inspection of the varied sequence of schists, gneisses, and other rocks in the T'ai-shan-ho section (Plate XVIII) will readily suggest that the interpretation of the Wu-t'ai system is both complex and difficult. Most of the strata have had their original components and structures obliterated by metamorphism. They have been intensely folded, and are interrupted by igneous rocks of several generations. In our brief reconnaissance, we did not succeed in unraveling the complexities of the stratigraphy and structure, but the facts observed enable us to add materially to previous knowledge of the region and to suggest explanations for many of the phenomena which must engage the attention of future students of the region.

The portion of the Wu-t'ai rocks exposed along our route seems to be divisible, on a lithologic basis, into three distinct groups, which we have named after appropriate geographic positions: 1. Shï-tsui group; 2. Nan-t'ai group; 3. Si-t'ai group.

The first group, Shï-tsui, comprises gray schists and gneisses with thick layers of quartzite. They occupy the eastern end of the T'ai-shan-ho section (Plate XVIII, beds 2–20). The Nan-t'ai group is characterized by dark quartzites and marble with subordinate schists. They are best exposed in the T'ai-shan-ho valley above Shang-ho-miau, and with them we have classed tentatively the white marble and schistose strata, which have been described as the Shang-ho-miau section, and which lie south of the typical Nan-t'ai sequence, separated from it by an overthrust. The third or Si-t'ai group consists largely of green schists, and includes the schistose clastics of coarse texture (Plate XVIII, beds 28–32). It forms the great mass of the main ridge of the Wu-t'ai-shan.

In the preceding pages the strata which constitute these three groups have been described as we observed them in the section on the T'ai-shan-ho. We now proceed to consider each group as a stratified sequence with the other groups. While not positive that we have correctly ascertained the true order of succession, we nevertheless begin with what we consider the oldest of the three.

Shï-tsui group.—The rocks which are assigned to this group are those which are described in the Shï-tsui section. We include in the group the

entire sequence, from the feldspathic quartzite next to the inferred unconformity, 2.5 miles, 4 kilometers, southeast of Shï-tsui, through the central mass of schists, to the contact of the quartzites and schists with the augen-gneiss 4 miles, 6.5 kilometers, above that village (Plate XVIII, beds 2–20). The rocks are dominantly mica-schists and gneisses with thick layers of quartzite and thinner bodies of amphibolite. All are of sedimentary origin.

If the strata in the Shï-tsui section succeed one upon another in monoclinal succession, the apparent thickness of the group is about 12,000 feet, 3,650 meters, subject to a correction for possible thickening in consequence of shearing, and for possible reduction of volume under anamorphic conditions.* But if the strata lie in a closed overturned syncline, as is suggested by gentler and steeper dips and by repetition of the quartzose beds, the Shï-tsui group consists of a lower alternation of dark schists and ferruginous quartzites (Nos. 2–10) and an upper mass of schistose pelites, arkoses, etc. (Nos. 12–18). The thickness of the former can be rather confidently estimated as being about 4,000 feet, 1,200 meters; while that of the mica-schists may be 2,500 feet, 760 meters, with a large correction for metamorphic changes as suggested above.

According to this interpretation of the structure and stratigraphy, the group of strata which lies next to the T'ai-shan complex, and which may with confidence be considered the oldest group of the Wu-t'ai system, consists of a normal sequence, from basal arkose, through heterogeneous psammites, to more uniform pelites. In spite of their immensely greater age, there is nothing that notably distinguishes these strata from the metamorphosed psammites and pelites of the Cambrian, in the New England province of the United States. Thus the oldest sediments of China indicate that processes of weathering and erosion similar to those of Paleozoic or present time were active in an ancient Pre-Cambrian age.

Nan-t'ai group.—In the southern part of the Wu-t'ai-shan section occurs a series of quartzites and siliceous marble. The quartzites are dark gray or reddish in alternating bands. Locally they are fissile and even schistose. The marble is similar in color and contains thin seams of slate and quartzite. The section is cut off by an overthrust, beneath which is a syncline in siliceous schists and white marble.

This group of strata—principally quartzite and marble—forms the lower part of Nan-t'ai, the southern peak of the Wu-t'ai range, and from that circumstance it is named the Nan-t'ai group.

*For discussion of this principle, see Van Hise, A treatise on Metamorphism, U. S. G. S. Monograph XLVIII, page 169.

The thickness of the Nan-t'ai group, measured from the lowest conglomerate of the Si-t'ai group to the overthrust fault, appears to be about 2,000 feet, 600 meters. Within this section obscure folds may cause reduplication of strata, and thus necessitate a reduction in our estimate of thickness. A further correction, which can not be calculated, is demanded by the changes in thickness attendant upon the development of schistosity in certain layers.

Strata of the Nan-t'ai group extend northeastward beyond the T'ai-shan-ho toward Tung-t'ai, a reddish quartzite assigned to the group forming the ridge 2½ miles, 4 kilometers, south of the peak.

The Shang-ho-miau section consists of coarse white marble, garnet-schists, biotite-schist, chlorite-schist, and dark quartzites, which, though mineralogically similar to the Nan-t'ai strata, are nevertheless separated from them by an overthrust fault, and are especially distinguished by the purity of the marble.

The overthrust between these two bodies of strata was observed in the canyon of the western branch of the T'ai-shan-ho and in the valley of the eastern tributary, north of Shang-ho-miau, and appears to be an important structural feature of considerable displacement. The strata on the overthrust side, the lower ones of the Nan-t'ai group, are probably older than those in the underthrust mass. Both groups are characterized by the presence of dark quartzites, marble, and schists. The degree of metamorphism is similar in the two cases. While each group contains rocks not present in the other, nevertheless the similarities seem to be more pronounced than the contrasts. Therefore we have mapped the rocks of the Shang-ho-miau section as Nan-t'ai, with a question.

On the northern slope of the Wu-t'ai-shan dark ferruginous quartzites were observed by von Richthofen and Willis in the O-shui valley. From the summit of Peï-t'ai similar resistant rocks were seen flanking the north side of the mountain. Here, as in the section just described, the quartzite appears to lie beneath the green schists of the Si-t'ai group.

Si-t'ai group.—The typical rocks of this group are the green chlorite-schists and phyllites of the central mass of the Wu-t'ai-shan. Along the southeast side of the outcrop they grade downward into schistose quartzites and arkoses, beneath which lie coarse conglomerate-schists. The chlorite-schists have the composition of non-ferruginous shales, and as they pass into the derivatives of quartzites we infer that they are of sedimentary origin.

The transition from shale downward through sandstone and arkose into conglomerate is highly suggestive of basal strata lying upon an unconformable contact. This contact is now so metamorphosed that it was

not distinguished in the field, but the evidence of the unconformity seems strong, and we regard the conglomerate as the base of the Si-t'ai group.

In the southern part of the Wu-t'ai section the Si-t'ai rocks appear to lie in a monocline, dipping steeply to the north. The conglomerates occur on the northern slope of the range south of Ts'a-pu, where they dip but 23° northwest, and, overlying magnetic quartzite, are themselves overlain by chlorite-schist. Thus the normal sequence is repeated in the same order and direction, without, so far as we observed, any intermediate occurrence in reversed order representing a southern dip. It is indeed highly probable that the chlorite-schists form a syncline in the crest of the range, comprising the summits Si-t'ai, Chung-t'ai, and Peï-t'ai, and that the above-noted repetition is due to an overthrust from the north, which cuts out the anticline that would otherwise lie adjacent on that side.

If this interpretation of the structure be correct, the uppermost strata are to be found along the summit of the range and may include the Peï-t'ai gneiss, if that rock be of sedimentary origin.

This group of conglomerate arkose and chlorite-schists, which makes up the mass of the Wu-t'ai-shan, is called the Si-t'ai group from the western peak of the range.

The original thickness of the Si-t'ai group can not be determined; the absence of distinctive strata and the intricate structure, involving schistosity, folding, and thrusting, render even an estimate worthless. The mass is, however, great, and probably was originally several thousand feet thick.

Correlation of the Wu-t'ai groups.—Of the three groups which make up the Wu-t'ai system, as we have divided it, the Shï-tsui group is apparently the oldest. It lies adjacent to and above the T'ai-shan complex; contains psammitic deposits derivable by erosion from that complex, and in all probability so derived; and exhibits a normal sequence of sediments, from the base upwards through coarser and finer psammites to pelites. It does not contain any pebbles of older sedimentary rocks, so far as we observed. We therefore place the Shï-tsui group at the base of the stratigraphic column, in a relation to the T'ai-shan complex similar to that of the lowest Algonkian on the Archean. In thus stating the position of the group, we would, however, avoid any implication of correlation closer than the most general parallelism of grand divisions.

Between the Shï-tsui and Nan-t'ai groups lies a mass of augen-gneiss, which interrupts the sedimentary sequence, and the base of the Nan-t'ai group is unknown, the lower part being cut off by an overthrust. The relation of the two groups is therefore indeterminate. We may speculate as follows: Since the Shï-tsui strata were heterogeneous sediments, grading upward from psammites to pelites, and the Nan-t'ai sediments were largely

carbonates with some fine-grained psammites and psephites, the latter may be related to the former as contemporaneous off-shore deposits to near-shore sediments; or may succeed the former in normal sequence, from psephitic sediments to carbonates.

In the one case the Nan-t'ai group would be equivalent to part of the Shï-tsui group. In the other case the Nan-t'ai group would overlie the Shï-tsui group, probably in conformable succession. We are unable to discriminate between these suggestions, but we regard the latter as more probable. There is the further possibility that the Nan-t'ai group may succeed the Shï-tsui unconformably.

In regard to the relation of the Nan-t'ai strata of impure marbles and quartzites to the beds of purer marble and quartzite in the Shang-ho-miau section, our inference is governed by the apparent structure. The syncline in the Shang-ho-miau section is thrust under the Nan-t'ai group, and the strata thus appear to be younger; yet the rocks are lithologically so similar that no notable difference of age is suggested. We suppose that the Shang-ho-miau section contains an upper part of the Nan-t'ai group, and that within that group there is a gradation upward, from fine psammites to impure and to purer carbonates.

The Si-t'ai group we regard as a distinct and younger division of the Wu-t'ai system, separated from the Shï-tsui and Nan-t'ai groups by an unconformity, and possibly overlapping on the T'ai-shan complex.

As no contact of the Si-t'ai and Shï-tsui groups was observed, our inference as to their relative ages is controlled by the relation of the Shï-tsui to the T'ai-shan complex, and by the presence in the Sï-t'ai of quartzite pebbles which may have been derived from the Shï-tsui strata. They may equally well have come from the Nan-t'ai strata, and our inference is qualified by that fact, but rests on the probability that the Nan-t'ai and Shï-tsui divisions are parts of one conformable sequence.

The relation of the Si-t'ai group to the Nan-t'ai is traceable in continuous section. We have drawn the line between the two at the coarse conglomerate, which we regard as a basal conglomerate, and which is in sequence with sediments that pass from coarse to finer, apparently from the base upward. The quartzite pebbles in the conglomerate are such as the Nan-t'ai rocks would furnish. There are also granite pebbles, and in the finer sediments occur arkose layers, which may have been derived from the T'ai-shan complex. It thus appears probable that not only the Nan-t'ai group but also the T'ai-shan complex was eroded during Si-t'ai time, and thus the unconformity between Nan-t'ai and Si-t'ai becomes one of notable duration; for the thickness of Pre-Si-t'ai strata, including the Nan-t'ai and probably the Shï-tsui terranes, is many thousand feet, and warping and

erosion must have been prolonged to expose the T'ai-shan. The deformation may also have involved folding, for our knowledge of the structure is not sufficient to exclude the possibility of unconformity by dip between the Nan-t'ai and Si-t'ai groups.

An overlap of the Si-t'ai terrane on the T'ai-shan complex is suggested by Willis's observations in the western Wu-t'ai-shan. He saw no considerable thickness of quartzites, such as we should expect in the position of the Nan-t'ai or Shï-tsui groups, between the Si-t'ai schists and the basal complex near the northern base of the range, and it is not probable that they could have been overlooked, even in a rapid ride, if they were present in characteristic form. Either they are replaced by mica-schists or are wanting. The latter seems more probable, and in that case the Si-t'ai group is, in this section, in contact with the T'ai-shan, in unconformable overlap.

Our inferences regarding the correlation of the groups of the Wu-t'ai system may be summarized as follows:

(*a*) The oldest rocks of the Wu-t'ai seem to be the Shï-tsui quartzites and schists.

(*b*) The Nan-t'ai group is probably younger, although it perhaps belongs to a conformable sequence.

(*c*) The Si-t'ai green schists are probably unconformable upon the Nan-t'ai strata and are regarded as the youngest group of the Wu-t'ai series.

Igneous Intrusives.

Igneous rocks do not play a conspicuous part in the Wu-t'ai district. With the exception of one or more batholitic masses of granite, the intrusions observed were all dikes, usually of moderate size. No superficial volcanic accumulations of any kind have been seen.

As these igneous rocks are of different ages, some of them profoundly metamorphosed, some moderately altered, and others essentially unchanged, we shall divide them, for purposes of description, into metamorphosed intrusives and unaltered dikes.

Metamorphosed intrusives.—Prominent among the metamorphosed intrusives are gneissoid granites, which occur associated with the green schists. A little more than a mile southeast of the village of Wu-t'ai-shan the wall of the canyon exposes a gneissoid granite, in which biotite is the principal dark mineral. The extent of this body northward was not determined, but at its southwestern edge it lies in contact with green chlorite-schist. The intrusive nature of the granite is proved by the dikes and veins of acid granite and pegmatite, which cut across the chlorite-schists abundantly in the neighborhood of the contact.

A similar granite is exposed along the T'ai-shan-ho, 2 miles, 3 kilometers, south of Shï-tsui, but in this case the relation of the granite to the adjacent rocks was not observed. It is possible that the gneiss in Peï-t'ai represents a third batholitic intrusion in the Wu-t'ai rocks, but of this the evidence is even less conclusive.

Black biotite-schist and hornblende-schist occur sparingly in dike-like bodies, which cut across the quartzites and schists of the Shï-tsui group. They are evidently ancient intrusives, which have been severely metamorphosed. A single thin sheet of serpentine was found interbedded with the gray augen-gneiss northwest of Shï-tsui, and on account of the known igneous origin of most other serpentines, this is presumed to be the metamorphic product of some basic igneous rock.

The most numerous dikes in the Wu-t'ai-shan region consist of greenish black schistose amphibolites, or greenstones, of fine texture. The dikes are 20 to 100 feet, 6 to 30 meters, thick, and they penetrate both the T'ai-shan gneisses and the Wu-t'ai schists. Similar greenstones have been found as dikes in the younger Hu-t'o strata. They are especially plentiful along the T'ai-shan-ho, between Shï-tsui and Wu-t'ai-shan.

Unaltered intrusives.—The remaining igneous rocks are as fresh as most Tertiary lavas; and so far as our observations go they consist only of siliceous porphyries. About 4 miles, 6.5 kilometers, northwest of Shï-tsui, there are numerous small dikes of quartz-porphyries. The rocks vary from blue-gray to pale brown and are distinguished by phenocrysts of quartz and feldspar. Four miles, 6.5 kilometers, farther up the river a thin dike of reddish-brown porphyry occurs, in which all of the phenocrysts are feldspars. Greenish hornblende-porphyries also were observed in a few places. They are usually much decayed, and aside from the black hornblende crystals, little can be distinguished in the hand specimen.

PRE-HU-T'O UNCONFORMITY.

In the typical district of the Wu-t'ai system, the Hu-t'o slates are the next overlying younger rocks. From the fact that the schists are profoundly metamorphosed and present an isoclinal structure, whereas the strata of the Hu-t'o series are but slightly metamorphosed and lie in more open folds, we infer with confidence that there is an unconformity between the two. Should the Hu-t'o series anywhere rest upon the T'ai-shan complex, as may very likely be the case, the unconformity would be still more pronounced.

Our route was not favorably conditioned for observation of the contact which is probably well exposed in the mountains west of Nan-t'ai and Shï-tsui (atlas sheet D I). From the summit of the peak 4 miles, 6.5 kilo-

meters, southwest of Shï-tsui, Sargent brought a specimen of typical gray Hu-t'o limestone, and reported that the beds dip gently southwest. The basal portion of this mountain is known to consist of highly inclined Wu-t'ai schists, and it is reasonable to infer that the unconformable contact of Hu-t'o series upon Wu-t'ai occurs in the upper slopes of the peak.

We have sketched the line of unconformity upon the map, according to the observed structure and inferences from distant views.

HU-T'O SYSTEM.

General statement.—Between the highly metamorphosed schists of the Wu-t'ai system and the unmetamorphosed strata of the Sinian system, we find in northern Shan-si a succession of strata consisting of slightly altered argillites and flinty limestones, which we have called the Hu-t'o system,* on account of the typical development in the hills near the Hu-t'o river, from Hin-k'ou to Tung-yü (atlas sheets B I and C I). The terrane is also wide-spread in the vicinity of Wu-t'ai-hién, which is the central point of the district in which we saw it.

It is distinguished from the Wu-t'ai schists by the very much more intense metamorphism of the latter, and the two are without doubt unconformable. From the Sinian or earliest Paleozoic it is separated by an unconformity, which marks a prolonged interval and various geologic changes. It is thus a Pre-Cambrian series, and of those which came under our observation it is the latest.

In its typical district we divide the Hu-t'o system into two groups, based on the probable structural relation of the detached and incomplete sections we were able to observe. The lower, consisting chiefly of slates or argillites interbedded with subordinate members of quartzite and crystalline dolomite, we name the Tóu-ts'un group, since the strata occur in the hills about that village. The upper group, which is composed of massive gray flinty limestone with thinner beds of argillite and quartzite, we call the Tung-yü group from its typical occurrence in the ridge east of that village.

The Tóu-ts'un group of the Hu-t'o system is known only in its typical locality in northern Shan-si. The Tung-yü group also is as yet recognized only in that district, unless we regard the Ta-yang limestone as its representative. Outside of the Wu-t'ai-hién region the Ta-yang limestone is of wide-spread occurrence. Judging from the descriptions given by von Richthofen, it is found not only in the mountains west of Peking, in the vicinity of the Nan-k'ou pass, but also toward the northeast, probably extending beyond the Great Wall; and in the vicinity of Töng-chóu-fu, in Shan-tung, similar rocks appear to be well developed.

*In all probability the Hu-t'o is the littoral phase of the siliceous limestones observed by von Richthofen in Nan-k'ou pass, northwest of Peking. If so, Nan-k'ou system has priority as a systematic term of general application, and Hu-t'o should be restricted to the local development of the strata.

Observed Sections.

Distribution.—The district within which the Hu-t'o strata occur in characteristic development lies southwest of the great Wu-t'ai-shan range and is the locus of a peculiar depression, which is to a great extent filled with the Huang-t'u or loess. Hills consisting of Pre-Cambrian argillite and limestone rise in isolated groups and ranges from the loess-filled basins. Similar rocks form the southwestern end of the Wu-t'ai-shan, and also occur in the base of the Ki-chóu-shan and its extension eastward.

Occurrences near Shï-tsui.—Rocks near Shï-tsui belong altogether to the older Wu-t'ai system, and the Hu-t'o strata did not occur in any of the sections which we observed along the T'ai-shan-ho and its tributaries. Four miles, 6.5 kilometers, southwest of the village there is, however, a conspicuous peak, which was occupied by Sargent as a triangulation station, and from which he brought back a characteristic specimen of limestone of the Hu-t'o system. We regard this as the most northeastern occurrence of these rocks at the end of the great synclinorium which stretches thence southwestward.

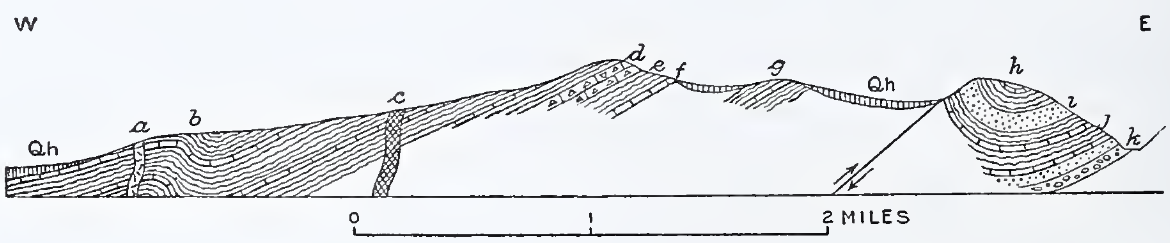


Fig. 21 (Blackwelder. Atlas sheet C I, section A A).—Liu-yüan, Shan-si. Tóu-ts'un slates and limestones (Upper Algonkian), exposed in the ridge east of Liu-yüan. *a* = porphyry dike; *b* = gray phyllites with thin reddish dolomite; *c* = greenstone dike; *d* = limestone breccia; *e* = gray slate; *f* = pure gray limestone; *g* = gray slate and reddish dolomite; *h* = gray slates; *i* = white quartzite; *j* = gray slate with gray and reddish dolomite; *k* = gray quartzite with conglomerate.

East of Liu-yüan.—The mountains east of Liu-yüan and south of Nan-t'ai-shan are composed almost entirely of the Hu-t'o rocks (Fig. 21). In the first ridge we found a series of earthy gray phyllites, the Tóu-ts'un slates, evidently derived from calcareous shales and in the early steps of metamorphism. The cleavage planes of these slates are frequently dotted with small crystals, which appear to be pseudomorphs of hematite after magnetite. Thin layers of red crystalline dolomite are intercalated with the slates at frequent intervals, and furnish a very convenient means of distinguishing the true bedding planes from the prevailing slaty cleavages Two and a half miles, 4 kilometers, southeast of this village the gray slates are overthrust from the west upon a syncline, which contains strata of an altogether different nature; white quartzite and limestone, with layers of gray phyllite interbedded, lie conformably upon gray and red quartzite, which contains local layers of conglomerate. What lies beneath the quartz-

ite is not visible. On account of the position of this section near the east end of the major synclinorium, it is not improbable that this is near the base of the Tóu-ts'un formation.

Vicinity of Tou-ts'un.—Seven miles, 11 kilometers, east of Tóu-ts'un there is a ridge formed of an alternation of gray and buff limestones with dark argillites and occasional white quartzites lying in a syncline. These strata resemble the Ta-yang formation of Chï-li more nearly than any other, but belong to the Hu-t'o system and probably chiefly to the Tóu-ts'un group. On the southeast this syncline is overthrust upon Sinian limestone and is thus discontinued.

Toward the northeast, where the ridge ends in a canyon which divides it from the slopes of Nan-t'ai, the Hu-t'o strata form the crest, but across the canyon we saw a thick and apparently continuous sequence of beds dipping steeply toward the north. They appear to be limestones or quartzites or both, interbedded with softer rocks, such as argillites or schists, and in dip and appearance correspond with the Wu-t'ai schists along the T'ai-

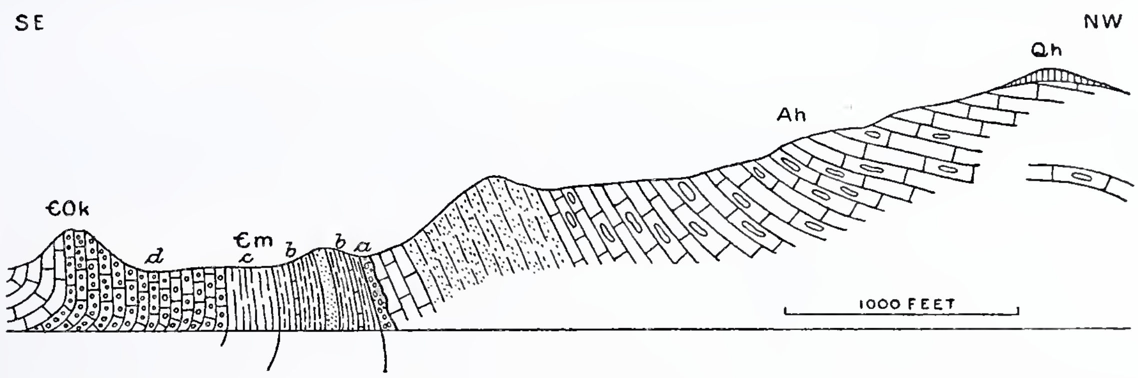


FIG. 22 (Willis. Atlas sheet C I, section E E).—Section across contact of Hu-t'o (Pre-Cambrian) strata unconformable to Man-t'o shale, showing basal conglomerate. *a* = highly ferruginous conglomerate, pebbles of quartzite, chert and hematitic-limestone, in matrix of hematite; *b* = siliceous limestone and quartzite with some shale; *c* = red shale; *d* = Ki-chóu oolitic limestone, fossiliferous.

shan-ho, 5 miles, 8 kilometers, distant in the direction of the strike. If this sequence is the southwestward extension of the Wu-t'ai rocks, the unconformity with the Hu-t'o strata, that form the upper portion of the peak from which our observation was made, should be found in the lower slopes. The moderate dips of the Hu-t'o contrast significantly with the steep isoclinal succession in the depths of the canyon, and an excellent opportunity is here afforded to determine the relations of the two systems.

The hills immediately south of Tóu-ts'un show banded cherty limestones of gray, buff, and pinkish tints, with thinner layers of white quartzite. The softer gray slates appear in the passes and slopes, but are largely covered by the alluvium and loess of the valley.

South by east of Tóu-ts'un the higher ridge adjacent to the Sinian outcrop is composed of hard gray flinty limestone, believed to be a part of the Tung-yü group. At the entrance to the canyon of the Shï-t'ou-ho

the limestone contains a layer of pink quartzite about 500 feet, 150 meters, thick, and the same bed appears again in a ravine further west (see Fig. 22). This succession is in both localities cut off by an unconformity with Cambrian strata, upon which the Pre-Cambrian is overturned and more or less overthrust.

Section of the Tóu-ts'un group.—Between Tóu-ts'un and Wu-t'ai-hién the Tóu-ts'un slates and portions of the overlying limestones are well exposed, and the structure enables us to make a fairly satisfactory although incomplete section (Fig. 23).

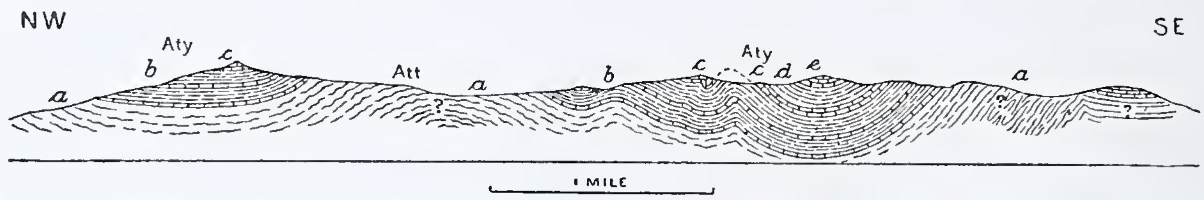


FIG. 23 (Blackwelder. Atlas sheet C I, section C C.)—Wu-t'ai-hién, Shan-si. Tóu-ts'un slates beneath Tung-yü limestones, etc. (Algonkian), exposed in the range east of the Wu-t'ai-hién basin.

e. Gray and pinkish limestone, accompanied by a light-colored limestone-breccia in an unknown relation.

d. Dark purplish argillite.

c. Gray and buff limestones, dense or finely crystalline. Contain parallel laminæ of flint, which are often curved and become prominent on the weathered surfaces .... 150 feet, 45 meters.

b. Purple argillite with thin beds of limestone and one or two of quartzite. The argillites show mud cracks and are not schistose .... 250 feet, 75 meters.

a. An unknown thickness of gray argillites which are usually slaty. Like the slates of Liu-yüan these frequently contain grains of hematite and local thin layers of red dolomite.

The basal member of this section is the equivalent of the gray slates at Liu-yüan, but in neither locality did we see what underlies them. The gray flinty limestones are regarded as belonging to the Tung-yü and bear a close resemblance to those of the Ta-yang formation in Chï-li.

Vicinity of Wu-t'ai-hien.—The phase of the Hu-t'o system which appears at the head of the canyon south of Wu-t'ai-hién is unfamiliar, but on structural data we infer that it belongs to the upper or Tung-yü formation. Here the lowest Sinian strata are overthrust by a pink quartzitic sandstone very similar to that associated with the gray limestone south of Tóu-ts'un (see Fig. 38). If our interpretation of the structure is correct, this is in turn overthrust by dark reddish limestone associated with dark argillites and hard gray limestones. The position of these rocks in the general section of the Hu-t'o system is unknown.

Section of the Tung-yü group.—The low range immediately east of Tung-yü is composed largely of limestones with interbedded soft slates; the prevailing colors are dark-gray, but light-gray, pink, and even buff layers are frequent. The purple slates outcrop only in the northern part of the range, where the limestones seem to lie upon them. A short distance

north of the pass by which the main road between Wu-t'ai-hién and Tung-yü crosses the ridge, the limestone contains about 100 feet, 30 meters, of thin-bedded impure limestones and argillites, which are bright red in color. Outcrops of this member, when viewed from a distance, may easily be confused with those of the red Man-t'o shales, which lie at the base of the Sinian in the same neighborhood.

At the northern end of this range we find red, white, and purple-gray quartzites, at least 500 feet, 150 meters, thick, lying upon the purple argillites; the relation here, as in so many other cases, is probably that of overthrust. The purplish quartzite contains many restricted layers of moderately coarse conglomerate. As exposed in cross-section these bodies are flat lenses and not continuous strata. Barring its consolidation, the deposit has a strong resemblance to the sands and gravels which are laid down by shifting streams. The pebbles in the conglomerate consist almost entirely of dark-purple quartzite with a few fragments of lighter-colored varieties; they are usually less than 6 inches, 15 centimeters, in diameter. The conglomeratic quartzite dips northward and is overlain by

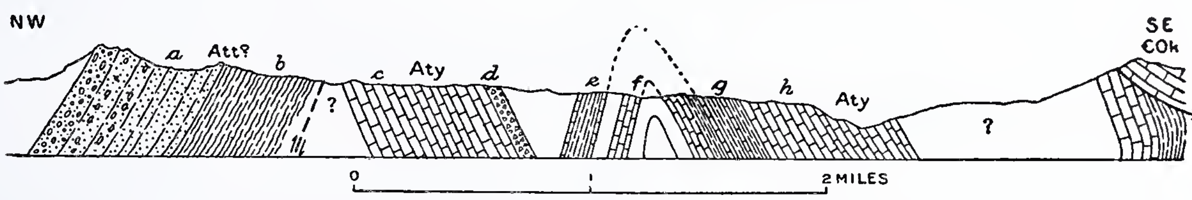


FIG. 24 (Blackwelder. Atlas sheet C I, section I I).—Tung-yü, Shan-si. Tung-yü (Algonkian) limestones. Incomplete section of gray limestone and slates associated with conglomeratic quartzite. *a* = dark-gray and purplish sandstone with seams of conglomerate; *b* = purple slates; *c* = flinty limestone, pink, white, and gray colors; *d* = hard quartz-breccia; *e* = gray and brown slates and red dolomite; *f* = gray flinty limestone; *g* = red shale and thin limestone; *h* = dark siliceous limestone.

light-colored quartzitic sandstone, which contains a few thin seams of earthy limestone. This unfamiliar phase of the Tung-yü rocks probably will be found to lie near the base of the system. The character of the rocks and the position of the exposure near the margin of the synclinorium argue for that view.

West of Tung-yü.—From Tung-yü westward the outcrops of this system are more restricted and isolated by wide expanses of the Huang-t'u. In the plain on the right bank of the Hu-t'o-ho an anticline of limestone of the Tung-yü group forms a low hill. The range immediately southwest of the Hu-t'o-ho consists of interbedded dark schistose argillites with reddish limestones and occasional quartzites, which we refer to the lower or Tóu-ts'un formation.

The mountain spur northwest of the town contains two massive gray limestones included in shaly strata of greenish and gray colors (see Fig. 25). These are apparently continuous with the rocks which form the

range on the east side of the valley, and, like them, doubtless belong to the Tung-yü formation.

In the Ki-chóu-shan.—Along the base of the high range which bounds the Hin-chóu basin on the south, we found the Tung-yü strata alternating in the foothills with the granites and schists of the basal complex. In the north slope of this mountain (Ki-chóu-shan) the folds and overthrusts have a more westerly trend than the recent normal fault-scarp. This, combined with the westerly pitch of the folds, causes the several formations to appear successively *en échelon* from under the Sinian strata, and disappear again under the plain to the westward.

The isolated hill south of Fang-lan-chön is composed of graywacke and coarse conglomerate, which are unlike any other rocks found in this district. They have been strained and slightly crushed, but are not severely metamorphosed. The pebbles of the conglomerate include quartzite scapolite-schist, and sericite-phyllite. Superficially the rock bears some resemblance to certain conglomerates of the Wu-t'ai system, but it is less metamorphosed and contains pebbles of schist which were probably

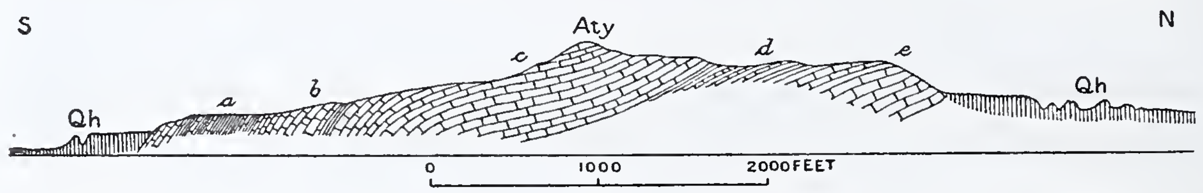


FIG. 25 (Willis. Atlas sheet C I, section J J).—Tung-yü Shan-si. Partial section of Tung-yü limestones and slates (Algonkian), in the ridge northwest of the town. *a* = green phyllite and thin ferruginous limestone; *b* = white and pink crystalline limestone with thin phyllite bands; *c* = buff and gray dense limestones; *d* = gray slate and thin ferruginous limestone; *e* = dense gray limestone.

derived from that older series. We, therefore, regard it as a part of the Hu-t'o system; and since it lies near the edge of the synclinorium and adjacent to an exposure of the T'ai-shan complex, we feel justified in thinking that it lies near, if not at, the base of the system.

At Chung-hua, southwest of the T'ai-shan outcrop, a complex of old sedimentary rocks is overthrust against the lower Cambrian. They comprise gray banded limestone and thin soft shales, red and white quartzites, and greenish argillites, with dikes of greenstone. Being only slightly metamorphosed, these are thought to be Hu-t'o strata.

South of Han-yang, gray crystalline limestones without any noteworthy amount of flint are the sole representatives of the Hu-t'o system. This phase is exposed in the outlying hills at the northern base of the high range, and extends southwestward past the Shï-ling gap and into the range which rises on the west. The strata are gray impure carbonate rocks with thin beds of soft gray slate; the sandy feel suggests dolomite. This saccharoidal limestone is an unfamiliar phase, which is included

in the Hu-t'o because it has no resemblance to any member of the Sinian system, and is comparable in some of its features to certain layers in the Tung-yü limestones.

Intrusions in the Hu-t'o System.

Igneous rocks do not occur frequently in the Hu-t'o system in this region. The most common are dikes of dark greenstone, which are now partly schistose. The gray slates southeast of Liu-yüan are penetrated by a few dikes of greenish hornblende-porphyry and greenstone. Three miles, 5 kilometers, south of Wu-t'ai-hién a single greenstone dike cuts the reddish argillites and limestone. Other similar intrusions, too deeply decayed to be identified specifically, are associated with the Hu-t'o strata south of Tung-yü and along the front of the Ki-chóu-shan.

Grouping and Correlation within the Hu-t'o System.

As already stated, the order of strata of the Hu-t'o system, as now understood by us, is deduced from an interpretation of the structure in the typical district. We have there a body of folded Pre-Cambrian strata, bounded on the southeast by a fault, along which they are overthrust on the Cambrian, and on the northeast and north by the older Wu-t'ai schists. According to the strikes and dips of this folded series, the pitch of the axes is toward the southwest. The folds sink in that direction and the synclines become deeper. The general structure may be regarded as consisting of two wide synclinoria, divided by an overthrust (geologic atlas sheet C I).

According to this interpretation of structure, strata about the margins of the synclinoria should be the older and strata in the central zones should be the younger. In a general way our observations indicate that there is a difference between the strata appearing in the general positions thus opposed. In the more northeasterly sections, soft slates associated with characteristic thin beds of limestone and quartzite prevail, and hills having a synclinal structure are capped by flinty gray limestones; whereas, toward the southeast, similar but thicker limestones associated with quartzite and thin beds of argillaceous rocks occur. On this basis we distinguish between an older and a younger group, namely the Tóu-ts'un slates below and the Tung-yü limestones above. The lowest of the Tóu-ts'un slates seen are supposed to be the beds of quartzite and conglomerate east of Liu-yüan, near the Wu-t'ai rocks and next the overthrust east of Tung-yü. The more massive limestone beds of the upper Tung-yü occur southwest of Wu-t'ai-hién adjacent to the Sinian limestones, and are with difficulty distinguished from the latter at a distance.

We are not able to give complete sections of either of these groups, or to point out a plane of demarkation between them. In view of the folding of the Hu-t'o system, it may be difficult to establish complete sections, even with detailed surveys, especially as the outcrops are limited

to the ridges surrounding the deeply filled loess basins. Our observations necessarily covered but a small part of even these available exposures, and in mapping we have delineated the general distribution only.

The best section of the Tóu-ts'un group is that observed between the Ts'ai-shï-ling and Wu-t'ai-hién. Strata similar to lower members of that section occur east of Liu-yüan.

The Tung-yü limestones are exposed in the ridge east of Tung-yü, and their stratigraphy is given in the description of that section. They were observed in isolated outcrops elsewhere, but no other continuous section was seen.

PRE-TA-YANG UNCONFORMITY.

The Ta-yang limestone, which, in Chï-li, is the probable representative of the Hu-t'o system, lies directly upon the T'ai-shan complex, the Wu-t'ai system being lacking. The general characteristics of the Ta-yang and T'ai-shan would lead us to anticipate an unconformity, and the fact was established by the observation of very good exposures.

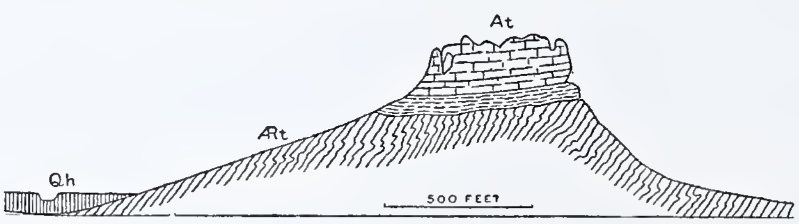


Fig. 26 (Blackwelder).—Wan-hién, Chï-li. Unconformable contact of Ta-yang limestone (Algonkian) upon T'ai-shan complex (Archean).

One occurrence is near Wang-k'uai-chön in the Fóu-p'ing district (Fig. 30). The basal shaly member of the limestone, dipping at a moderate angle, lies in manifest unconformity upon the weathered and eroded surface of the gneiss. The high hill immediately east of Fóu-p'ing-hién consists mainly of gneiss, but is crowned by nearly horizontal shales and flinty limestone of the Ta-yang.

Six miles, 9.5 kilometers, northwest of Wan-hién, a castellated butte affords an admirable exposure of the unconformity (see Fig. 26). The top of the butte consists of 110 feet, 33 meters, of the typical flinty limestone of the Ta-yang formation, beneath which are 10 to 15 feet, 3 to 4.5 meters, of gray calcareous shales. The shales lie directly upon the gneiss, without the intervention of any conglomerate or arkose. The exposure is too limited to show any considerable extent of the surface of the basal complex, but the ancient topography seems to have been only slightly undulatory. The plain extends across the truncated edges of the layers in the gneiss.

In the trip to Nan-t'ang-meï, Willis observed the cherty limestone within 16 feet, 5 meters, of mica-gneiss of the T'ai-shan complex. The limestone dips gently northwest and lies at the base of the great thickness

of strata exposed in the mountain for 3 miles, 5 kilometers, in that direction. The outcrop of this unconformity continues west by south, past Si-ta-yang, and thence off under the alluvial plain. West of Ta-yang both the gneiss and the limestone have been reduced to low hills, and the contact is largely concealed beneath the Huang-t'u.

TA-YANG FORMATION.

General statement.—In western Chï-li we found extensive occurrences of a massive flinty gray limestone, the Ta-yang formation, which we named after the village of Si-ta-yang in the T'ang-hién district. It is separated from the Archean below and from the Cambrian above by pronounced unconformities, and belongs in the Algonkian. We regard the Ta-yang as equivalent to the Hu-t'o system of Shan-si and the Nan-k'ou limestone of von Richthofen.

The Ta-yang formation is dominantly a limestone of gray color and dense texture. Von Richthofen found the formation in the Nan-k'ou mountains in northern Chï-li, lying beneath the known Sinian system in a position which led him to think that there was no stratigraphic break between them.* He therefore believed it to be a great marine phase of the

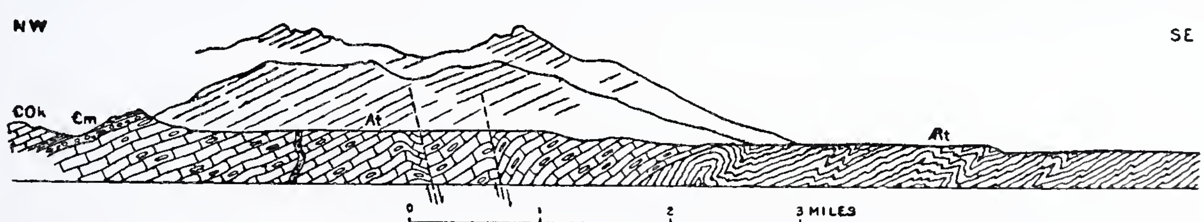


FIG. 27 (Willis. Atlas sheet F I, section AA).—T'ang-hién, Chï-li. Ta-yang (Algonkian) limestone lying upon T'ai-shan (Archean) gneiss. Cambrian strata and unconformity on the left.

lower Sinian. When, however, we had established the difference between them by observation of the unconformity, we recognized certain persistent characteristics, which should render them easily separable. Limestones of the Ta-yang (Nan-k'ou) system are rich in laminæ and nodules of flint, in strong contrast to Sinian limestones, which are almost totally devoid of flint. Quartzite also appears at many horizons in the Ta-yang, but it has not been observed in the Sinian. Conversely, the dark oolitic and conglomeratic limestones, which are so characteristic of certain horizons in the Sinian, are not known in the older series. Fossils are abundant in the lower part of the Sinian, but none have been found in the Ta-yang.

DISTRIBUTION.

The Ta-yang limestone occurs in the low mountains which border the alluvial plain north of Wan-hién, and trends thence southwestward to the Sha-ho and beyond. It is well exposed in the mountains between T'ang-hién and Nan-t'ang-meï, and also between Si-ta-yang and Ning-shan. Small

*Von Richthofen, China, vol. II, page 317.

areas occur southeast of the village of Wang-k'uai-chön and near the town of Fóu-p'ing-hién. These occurrences lie in belts or isolated patches, generally bounded by outcrops of the T'ai-shan complex, but in the vicinity of Ning-shan overlaid by Sinian strata. A statement of the sections which we observed follows.

Vicinity of Wan-hién.—On the border of the plain northwest of Wan-hién, the Ta-yang rocks were found in contact with gneiss which is overthrust upon them from the southeast (see Figs. 28 and 29). A short distance westward, however, the limestones lie undisturbed upon the gneiss. The lowest rocks in the section here exposed are gray-white calcareous shales, which are slightly metamorphosed. This basal member varies in thickness from a few inches to 30 feet, 10 meters, or more. It is followed by an unknown thickness of gray flinty limestones, with which

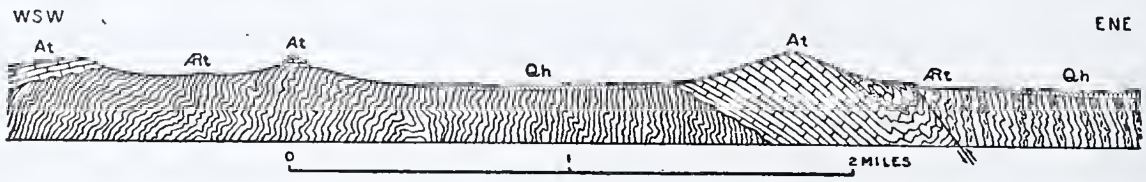


FIG. 28 (Blackwelder).—Wan-hién, Chï-li. Section of low hills north-northwest of city, showing Pre-Cambrian granite overthrust upon Ta-yang (Algonkian) limestone on the right, but lying unconformably beneath it on the left.

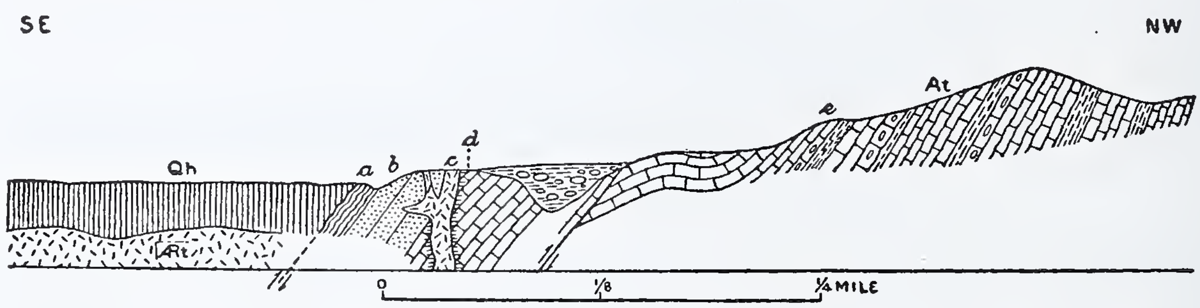


FIG. 29 (Blackwelder).—Wan-hién, Chï-li. Pre-Cambrian granite overthrust upon Ta-yang (Algonkian) limestone in the edge of the alluvial plain northwest of the city. *a* = muscovite-schist along fault-plane; *b* = white quartzite; *c* = aplite dike; *d* = gray limestone with tremolite crystals; *e* = dense gray limestone, with shale.

are associated thin seams of quartzite and schists. The limestone is usually banded with light- and dark-gray colors, but there are also considerable masses which are clear gray, yellowish, or even white. The composition of the rock is somewhat variable. There are earthy varieties, the weathered surfaces of which are covered with an ashy residue; there are also highly siliceous members, which are very hard and dense and have a conchoidal habit of fracture; also nearly pure limestones, belonging to the clear-gray flintless member. The siliceous and pure varieties occur in moderately thick strata, evenly bedded; the earthy rocks are thin-bedded or shaly. At many horizons in the limestones flint is abundant. It occurs in nodules, in nodular layers, and in groups of thin parallel laminæ which are often wavy or even curved in peculiar designs, having little relation to the stratification of the rock and not due to the mechanical deformation

of the strata. The nodular layers and laminæ are much more abundant than the separate nodules. They are usually blackish in color, but are sometimes gray or white. The thin quartzites, which have been mentioned as constituents of this limestone series, are usually white in color and occur in isolated beds 5 or 6 feet, 1.5 or 2 meters, in thickness. The entire sequence at this place is estimated at about 1,200 feet, 375 meters.

The limestone is apparently overlain by a series of soft rocks, which consist partly of quartz-biotite, and sericite-schists, alternating with several layers of white quartzite. The thickest of these quartzites form several low ridges, which barely rise above the alluvium at the base of the limestone hills. The schist and quartzite group was not observed at any point beyond this locality northwest of Wan-hién.

Vicinity of T'ang-hién.—The belt of the Ta-yang limestones was crossed three times in the region northwest of T'ang-hién. The gray, flinty limestones were found lying upon the basal complex and dipping gently northward (Fig. 30). Along much of the northern edge of the exposure the Sinian limestones are overthrust upon the older rocks and cut off whatever may have overlain the Ta-yang limestones. Near Nan-t'ang-meï, however, the fault apparently dies out and the uppermost Ta-yang limestones are overlain by about 100 feet, 30 meters, of conglomeratic breccia (Fig. 27), which consists almost entirely of rounded pebbles and fragments of black, white, and banded flint, embedded in a hard siliceous matrix. Upon this lies a quartzite 50 feet, 15 meters, thick, which is in turn followed by more than 60 feet, 18 meters, of dark purple argillite. The conglomerate breccia was at first taken for a silicified fault breccia, but was found to have a more definite stratigraphic position and greater extent in the adjacent hills than would be expected. It exhibits a tendency to bedding and dips gently northwest with the overlying Sinian shales. From the underlying Ta-yang limestone, chert weathers out in great abundance and should occur in any basal conglomerate of an unconformable younger formation. The petrographic examination of a specimen of the conglomeratic shows it to be of sedimentary clastic origin. Thus we are led to conclude that it is a peculiar local deposit at the base of the Sinian, the lowest Sinian being elsewhere in this district and generally a red shale. Limited deposits of conglomerate of various local materials were, however, seen at several points in Shan-si. The silicified mass of the conglomerate-breccia is closely sheared on planes which strike N. 30° W. and dip 70° to 85° NE. It may also have been a plane of thrusting, and probably exhibits the characters of an auto-clastic rock as well as those of a basal conglomerate, though the particular specimen collected does not, under the microscope, show effects of strain.

The village of Si-ta-yang is situated near the contact of the flinty limestones and the gneiss. The strata dip gently northward at first, but

after a space of a mile or more, they are involved in moderate folds and are finally cut off on the north by the overthrust mentioned above. To the west of the village the Ta-yang formation is broadly exposed in low hills which are partially soil-covered. This area continues southwestward north of the city of Kü-yang-hién, for an undetermined distance. The base of the section near Ta-yang was not actually observed owing to the fact that the contact is largely obscured by the soil of the surrounding lowland, but not more than 20 feet, 6 meters, above the gneiss the strata are gray flinty limestones of fine texture and somewhat argillaceous composition. Freshly broken surfaces appear clean and uniformly gray in color, but the weathered exteriors are ash-gray and are covered with an earthy residuum. These gray limestones, in which nodules and laminæ of flint are abundant, continue upward through a thickness which, though not determined, is estimated at several thousand feet. At certain horizons the strata are dark in color and less purely calcareous. About 800 feet, 240 meters, above the base, a thirty-foot layer of white quartzitic sandstone appears in this locality. Aside from these slight variations, the sequence is notably uniform. The flint nodules which are so characteristic of the formation are usually black, but it is not rare to find cherts of a white or buff color.

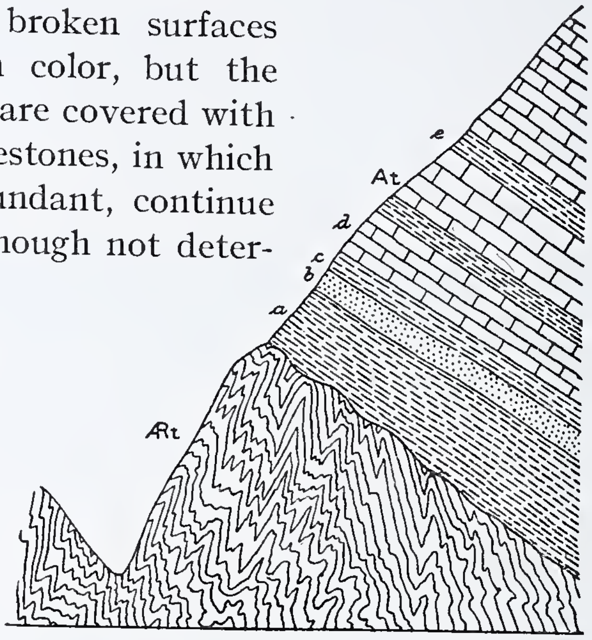


FIG. 30 (Blackwelder).—Wang-k'uai-chön, Chï-li. Unconformity beneath Ta-yang (Algonkian) limestone, showing basal shales lying upon weathered and eroded gneiss (Archean). *a* = calcareous brown shales, micaceous at the base; *b* = impure sandstone; *c* = gray calcareous shale; *d* = gray limestone; *e* = gray flinty limestone with thin layers of gray and buff shale.

In the hills east of Wang-k'uai-chön, the basal complex lies against the Sinian limestone along a normal fault. Upon this upthrown block of the complex there is an outlier of the Ta-yang limestone, representing several hundred feet of the formation (see Fig. 30). In this case the basal portion consists of shales, quickly followed by a sequence of gray flinty limestones.

A similar outlier, exhibiting only 200 or 300 feet of the sequence, is situated about a mile, 1.5 kilometers, east of Fóu-p'ing-hién, in the summit of the mountain, upon which a temple is built. Here also the limestones lie unconformably upon the basal complex, with a thin member of red-brown shales intervening.

Igneous Intrusions in the Ta-yang Limestones.

There is a notable absence of igneous rocks in connection with the a-yang limestone throughout the area explored in western Chï-li. Near the overthrust which brings the gneiss up against the limestone northwest of Wan-hién, several small dikes of white aplite and fine-grained granite have been intruded into the sedimentary rocks. Along the contact with these dikes the limestone contains abundant crystals of pale amphiboles such as tremolite. In addition to these occurrences a small dike of brown-gray quartz-porphyry was found by Willis in the Ta-yang, a few kilometers north of T'ang-hién. No basic intrusives nor large batholites of any kind were observed.

Correlation of the Hu-t'o and Ta-yang.

In the general statement regarding the Ta-yang we have already stated our opinion that the limestone is to be correlated with the Hu-t'o system. Both are late Algonkian terranes, which have not been notably metamorphosed or intensely folded. Although the Ta-yang limestone has not been found in contact with the Wu-t'ai schists, there can be no reasonable doubt that, like the Hu-t'o, it is very much younger. Both the Ta-yang and Hu-t'o are unconformably, but immediately, overlain by the Sinian.

The Hu-t'o system is believed to consist of a lower slaty group, in which thin limestones occur. The Ta-yang, however, is calcareous throughout and is lithologically similar to the limestone of the upper group of the Hu-t'o system. Between the localities at which we saw the two limestones there is a distance of 50 miles, 80 kilometers. The lithologic resemblances and differences are such as are consistent with equivalency, but they are not sufficient to establish it. The Ta-yang limestone may represent the whole of the Hu-t'o system, or only the upper limestone group; or it may possibly lie between the latter and the Sinian. The two groups, however, range themselves among the latest Pre-Cambrian formations, closely resembling the late Algonkian rocks of the northern Rocky Mountains in Montana, and we regard it as improbable that they lie in succession rather than as equivalents.

It is not improbable that the Ta-yang limestone is the more uniform representative of the partly heterogeneous shore formations, which we distinguish as the Tóu-ts'un and Tung-yü groups.

There can be little doubt that the Ta-yang limestone is the exact equivalent of that observed by von Richthofen in the Nan-k'ou section and described by him as "Untersinisch."

PALEOZOIC.

By Eliot Blackwelder.

PRE-SINIAN UNCONFORMITY.

Out of the thirteen instances in which Sinian rocks were found in contact with older systems, four were fault contacts and the rest were visible erosion unconformities. Among the latter, the rocks which underlie the Sinian were in four cases the T'ai-shan complex, in two cases the Wu-t'ai schists, and in two cases the Hu-t'o system. Five of these exposures, each of which presents distinctive features, are here described.

About 7 miles, 11 kilometers, southeast of Hin-chóu, in the north slope of the mountain, the red granite of the T'ai-shan complex lies upon the upturned edges of the Sinian strata on a gently sloping overthrust plane (Fig. 31). Below the fault, however, the Lower Cambrian sediments rest undisturbed upon the eroded and weathered surface of the granite. The basal layer of the Cambrian shales consists of a few inches of coarse arkose sand, composed of the red feldspars and blue-gray quartzes derived from the granite. This sandstone is followed as usual by the red shales.

Another excellent exposure of the unconformity appears in the slopes of a valley 3 miles, 5 kilometers, south of Yau-t'óu in Shan-si (Fig. 46). On the west side of the valley the Cambrian red shales lie upon the eroded edges of white quartzite, embedded in dusky biotite-schists. In the opposite slope the contact is upon purplish biotite-schists. There is a close similarity between these schists and certain members of the Wu-t'ai system southeast of Shï-tsui. The ancient surface at this point is nearly plane and the rocks are deeply weathered. A greenstone dike, which had penetrated the schists in Pre-Sinian time, is squarely cut off at the unconformity. Contrary to the usual composition of the Cambrian shales, the basal portion here is composed of 15 feet, 4.5 meters, of coarse sandstone and conglomerate. The constituents of the pebbles are banded chert and white, red, and black quartzites, all of which rocks have been found in the Wu-t'ai and Hu-t'o systems.

At Yen-t'ou north of Wu-t'ai-shan, the cliffs of the O-shui canyon expose the Sinian limestones and shales lying in marked discordance on the green Si-t'ai schists (Lower Algonkian). (Plate XIX and Fig. 34.) The schists are weathered and brownish at the contact, and the basal member of the Cambrian is a thin conglomerate of quartz pebbles. Red sandy strata overlie the conglomerate and are in turn followed by red shales, all belonging to the Man-t'o formation.

In the fourth example the Cambrian rests upon the Hu-t'o strata, thus proving the Pre-Paleozoic age of the latter. The older rocks consist

of dark argillites and siliceous red limestones, inclined at high angles and cut by greenstone dikes. The Cambrian, resting upon the truncated stumps of these strata, dips gently southward (Fig. 33). At the base of the Sinian there is a dark red conglomerate with sandy matrix. The fact that this varies in thickness from nothing to 20 feet, 6 meters, or more indicates that the Pre-Cambrian topography in this region possessed slightly more noteworthy relief than in other localities examined. The conglomerate contains quartzites, and also purplish argillites and limestones like those beneath it. This contact, which is to be seen about 4 miles, 6.5 kilometers, to the south of Tung-yü, is exposed with exceptional clearness.

The fifth example is from the base of the Ki-chóu-shan, not far from the contact shown in Fig. 31, but the Pre-Cambrian is represented by the greenish argillites, probably of the Hu-t'o system, which are cut by a basal dike that ends at the unconformity (Fig. 32).

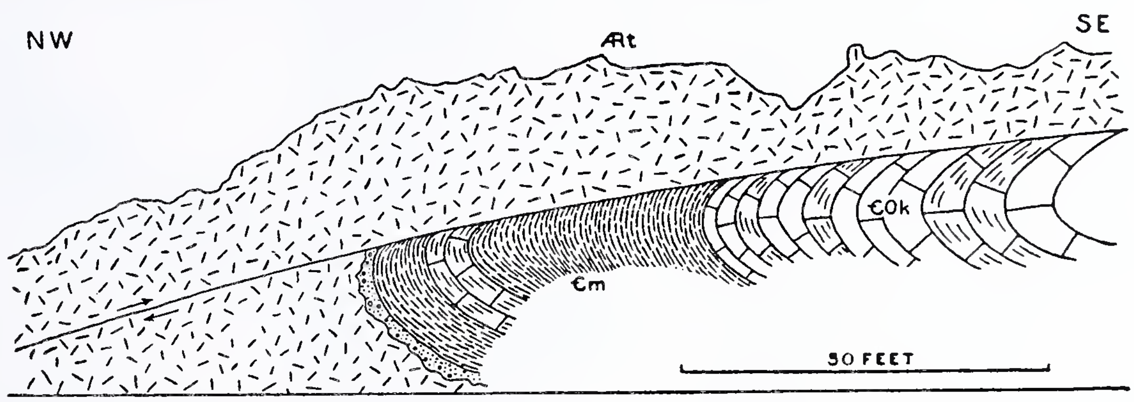


Fig. 31 (Blackwelder. Han-yang, Shan-si, atlas sheet B II).—Unconformable contact of Cambrian shales upon Pre-Cambrian granite, beneath an overthrust mass of the latter. Foothills of Ki-chóu-shan southeast of Han-yang.

From these examples it appears that, before the Sinian sediments were laid down, the older rocks had been folded and eroded until all three of the Pre-Cambrian systems had been exposed in various areas.

SINIAN SYSTEM.

General statement.—The Sinian rocks were found in three localities in the mountains between Pau-ting-fu and T'ai-yüan-fu: (1) near Ning-shan in Chï-li, (2) along the southern edge of the Wu-t'ai-shan district, and (3) on the northern flank of the Wu-t'ai range. As it is developed in those areas, the system consists of only two distinct formations; a basal group of reddish shales, sandstone, and impure limestone, and a thick series of grayish limestone, which, while presenting some internal variations, is fairly uniform and can not readily be subdivided.

For the first of these we propose to extend from Shan-tung the name "Man-t'o formation," because the red shales of the two provinces are

lithologically similar, occupy the same stratigraphic position, and are probably contemporaneous. For the second group, which apparently covers both the Kiu-lung and Tsi-nan groups of Shan-tung, the name "Ki-chóu group" is suggested, because a complete section of the Sinian system is exposed on the precipitous front of the Ki-chóu-shan south of the Hin-chóu basin.

The Man-t'o formation in Shan-si differs considerably from the type section in Shan-tung. At the base, arkose, conglomeratic, or tufaceous sandstones, of variable but slight thickness, are succeeded by an alternation of red sandy and calcareous shales with reddish buff, or argillaceous limestones.

In most sections one or two very thin, but persistent, bands of gray-green quartzite occur not far above the middle of the formation. The red shales are often massive and relatively hard. The total thickness of the Man-t'o varies from 180 to 335 feet, 55 to 100 meters, or about one-half as great as its representative in Shan-tung. The upper limit is fairly definite at the base of the grayish limestones of the succeeding formation. No fossils were seen in the formation outside of Shan-tung.

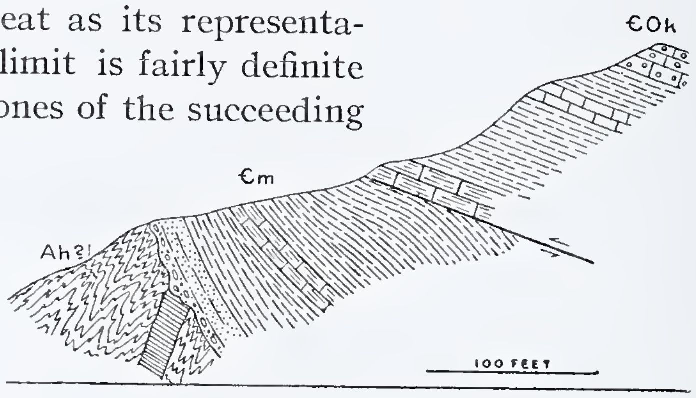
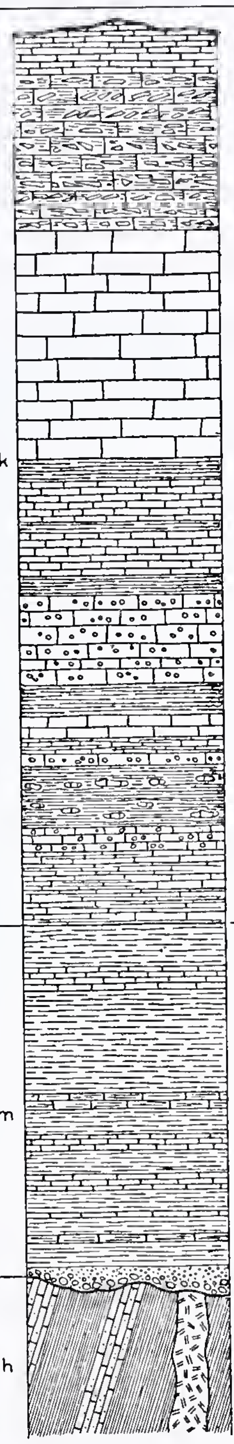


FIG. 32 (Blackwelder. Chung-hua, Shan-si, atlas sheet B II).—Man-t'o (Cambrian) red shales lying unconformably upon Pre-Cambrian metamorphic rocks at the base of the Ki-chóu-shan.

The massive Ki-chóu limestone comprises gray, greenish, and dark brown rocks, such as are characteristic of the Sinian in Shan-tung. Certain layers are oolitic and conglomeratic, but in strong contrast to the Algonkian limestones they are never flinty.

The base of the limestone usually consists of alternate gray and greenish limestones, interbedded with calcareous shales of like color. The shales, however, make up but a small thickness of the section. Between the red shales and the dark upper limestones we have a thickness of about 600 feet, 180 meters, of these thin-bedded grayish limestones. This part of the formation includes the dark oolites and conglomeratic layers, which are in most respects similar to those already described from Shan-tung. It has yielded a considerable variety of fossils of Middle and Upper Cambrian age.

The upper portion of the formation, surmounting the above section through a thickness of more than 2,000 feet, 600 meters, consists almost uniformly of massive dark dolomitic limestone, similar in all its peculiarities to the Tsi-nan limestone of Shan-tung. Like that formation it rarely affords fossils.



			Feet.	Meters.	
Cambro-Ordovician.	Ki-chóu limestones.	€Ok	20+	6+	Dense blue limestone.
			75	23	Ocherous, gray, dense, conglomeratic limestone.
			110	33	Massive ocherous gray limestone.
			65	20	Brown and gray shales and thin-bedded limestone.
			45	14	Massive gray oolitic limestone.
			15	4.5	Gray shales.
			9	3	Gray crystalline limestone.
			8	2.5	Gray calcareous shale.
			5	1.5	Oolitic limestone.
			30	9	Gray and buff shales with limestone nodules.
			12	3.5	Hard brown-gray oolitic limestone.
			35	10.5	Slabby buff limestone, dense and hard.
	Man-t'o shales.	€m	80	25	Red shales with thin reddish limestones.
			40	12.5	Red shale and argillaceous limestone with thin yellow limestones.
			30	9	Red shale and thin limestone.
			4	1.3	Argillaceous yellow limestone.
			12	3.5	Red calcareous shale.
			3 to 15	1 to 5	Red sandstone and conglomerate.
Algonkian.	Hu-t'o System.	Ah	610+	180+	Purple argillites; siliceous limestones and dikes of greenstone.

FIG. 33.—PARTIAL SECTION OF THE SINIAN SYSTEM SOUTH OF TUNG-YÜ, SHAN-SI.

STATEMENT OF OBSERVATIONS.

Vicinity of Ning-shan, Chï-li.—In western Chï-li the Sinian is exposed in a syncline near Ning-shan (Figs. 48 and 49). The outcrop extends in a broad belt from the Sha-ho on the west, a distance of more than 25 miles, 40 kilometers, east-northeast. On the north side of this belt the Sinian rests in contact with the T'ai-shan gneiss, along a normal fault;

at the southern edge it is overthrust upon the Ta-yang limestone, except in the vicinity of Nan-t'ang-meï, where the fault dies out. The succession of strata within the mass is interrupted by many internal faults.

The red shales of the Man-t'o formation occur northwest of Ning-shan, in the base of the high flat-topped mountain and in some of the neighboring ridges, but the rocks are so badly broken by normal faults that the measurement of a section was not attempted. The base of the Man-t'o was not seen. The lower members of the Ki-chóu limestone form the top of the mountain and most of the range of which it is a part.

On the south side of the Ning-shan basin the Ki-chóu limestone is moderately folded and is overthrust upon the Algonkian. The outcrop widens eastward, as the throw of the fault decreases, until near Nan-t'ang-meï the oolitic and conglomeratic limestones of the Middle Cambrian appear at the base of the Ki-chóu. In this vicinity Willis observed unfamiliar strata, which are now believed to represent the Man-t'o formation. They consist of dark massive argillite lying upon white quartzite, 50 feet, 40 meters, thick. The latter rests unconformably upon the flinty gray limestone of the Ta-yang (Algonkian) series. The base of the quartzite is a conglomerate composed of angular fragments of dark and banded flint from the Algonkian terrane. This conglomerate is the chief evidence of unconformity, for the older and younger rocks coincide in dip (Fig. 27, p. 131).

No fossils were collected in this region. The dark Ordovician limestone is as barren here as in Shan-tung, and the Cambrian is rarely exposed.

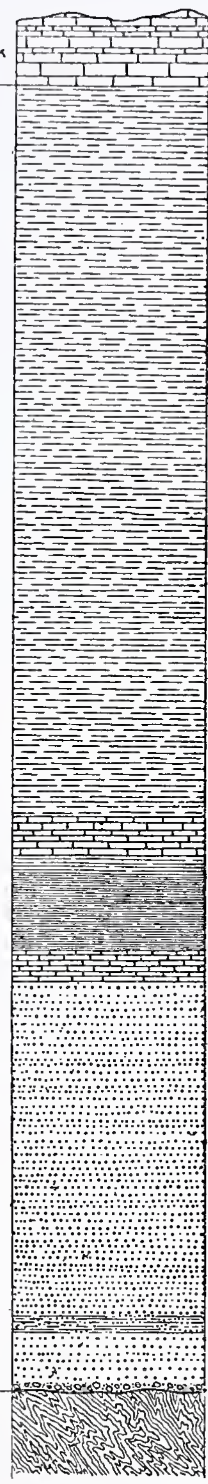
At Mi-chöng the upper Sinian limestones are cut by a large dike of buff-colored feldspar-porphyry. This is the only dike we observed traversing Sinian rocks in the mountains between Pau-ting-fu and T'ai-yüan-fu.

South of Tai-chóu, Shan-si.—Von Richthofen has admirably described the picturesque cliffs of Sinian limestone in the valley of the O-shui, north of Wu-t'ai-shan* (see Plate XIX). The section in Fig. 34 was measured by Willis in 1904 in the same canyon. The Man-t'o formation rests directly upon decayed schists of the Wu-t'ai system. The lower portion is red sandstone and sandy shale, while shales with thin limestones predominate at higher horizons. The red shales are capped by 2,700 feet of Cambro-Ordovician limestone, which forms the Ki-chóu formation. Fragments of Cambrian fossils were seen in the talus which had fallen from the cliffs.

Vicinity of Tóu-ts'un, Shan-si.—From a point about 6 miles, 10 kilometers, southwest of Shï-tsui the Sinian rocks extend west-southwest in a broadening syncline, far beyond T'ai-yüan-fu. By virtue of their hardness and the recent uplift to which they have been subjected, they rise in mountains which maintain a nearly continuous northern front 2,000 to 4,000 feet, 600 to 1,200 meters, high, along the lowlands occupied by the towns of Wu-t'ai-hién, Hin-chóu, etc. The highest part of this range is known as the Ki-chóu-shan.

*China, vol. II, page 365.

Near Yen-t'óu in the Wu-t'ai-shan, atlas sheet C I. View in lateral canyon of the O-shui-ho, showing unconformity between the Pre-Cambrian Si-t'ai schists (Ws) and Cambrian shale (€m).



			Feet.	*Meters.*	
Cambro-Ordovician.	Ki-chóu.	€Ok			Limestone, thin-bedded below and thicker bedded above, to top of cliff about 2,700′ above the Pre-Cambrian.
	Man-t'o.	€m	188	57	Red shale.
			10	3	Yellow limestone.
			4	1.2	Green shale.
			20	6	Purple shale.
			8	2.4	Yellow limestone.
			87	26	Sandstone.
			4	1.2	Sandy shale.
			12	3.6	Red sandstone.
			2	.6	Conglomerate.
	–Unconformity–				
Algonkian.	Si-t'ai.	As			Chlorite-schist.

FIG. 34 (WILLIS).—YEN-T'OU, SHAN-SI. MAN-T'O FORMATION (CAMBRIAN) LYING UPON SI-T'AI (ALGONKIAN) GREEN SCHIST IN CLIFFS ALONG THE O-SHUI, NORTHWEST OF WU-T'AI-SHAN.

The valley of the Shï-t'ou-ho south of Tóu-ts'un affords several sections of the Sinian. East of the river the rocks lie in a sharp syncline, overthrust from the north by Algonkian schists and limestones (Fig. 35). The overthrust lies near the base of the Sinian, and at times cuts out

part of the Cambrian sequence. The Man-t'o shale is represented here by several hundred feet of red shales, sandstones, and sandy shale. The lower portion of the Ki-chóu consists of thin-bedded gray and greenish limestones and shales. The limestone is locally oolitic and fossiliferous. More massive barren limestones of gray color form the higher section.

At the head of the Shï-t'ou-ho canyon a much-faulted syncline of the lower part of the Sinian is overthrust upon the dark upper limestones which form the precipitous walls of the gorge (Fig. 37).

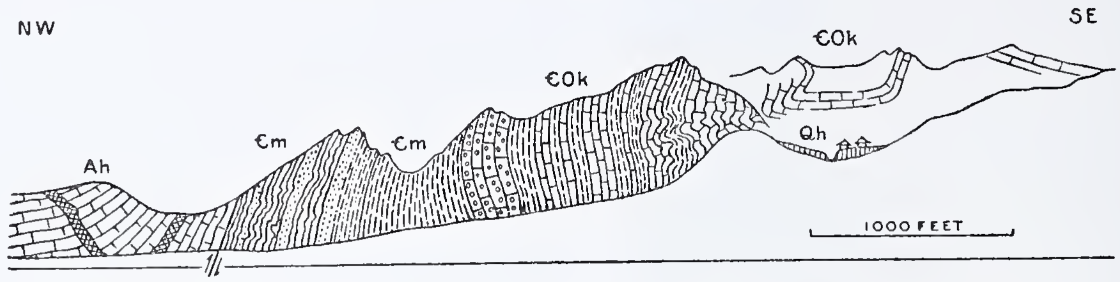


Fig. 35 (Willis. Atlas sheet C I, section BB).—Tóu-ts'un, Shan-si. Lower Sinian (Cambrian) strata overthrust by Hu-t'o (Algonkian) limestone, 6 miles, 9.5 kilometers, east of Tóu-ts'un.

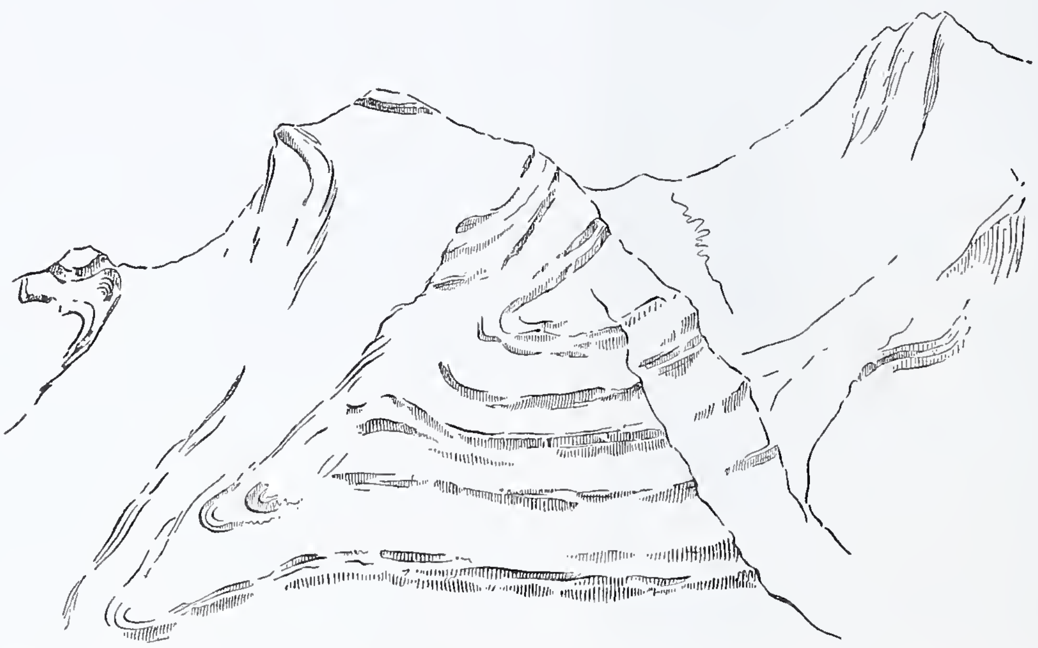


Fig. 36 (Willis).—Sketch of overturned syncline in Ki-chóu (Cambro-Ordovician) limestone, in the mountains east of Tóu-ts'un, Shan-si.

In the next valley southwest, which heads in a wind gap in the front range, the Cambrian sequence is better exposed (Fig. 22). At the base a conglomerate and sandstone cemented with hematite lies overturned beneath the Tung-yü (Algonkian) limestone. The pebbles are composed of jasper, quartzite, and flint, from the older rocks. This richly ferruginous stratum is followed by red, brown, and green shales and thin gray limestones, composing the Man-t'o formation. The lower shaly limestones of the Ki-chóu group come in over them with characteristic features.

South of Wu-t'ai-hién.—On the west side of the Sing-ho, below the city of Wu-t'ai-hién, lower Sinian rocks are exposed in a narrow gorge. They lie in a syncline, cut off on the south by Algonkian rocks which have been overthrust upon them (Fig. 38). The section reveals the upper part of the Man-t'o formation and a small thickness of Middle Cambrian limestone. The Man-t'o includes red-brown shales with thin green bands and seams of greenish quartzite. The limestones are gray with a greenish tinge, and are locally oolitic.

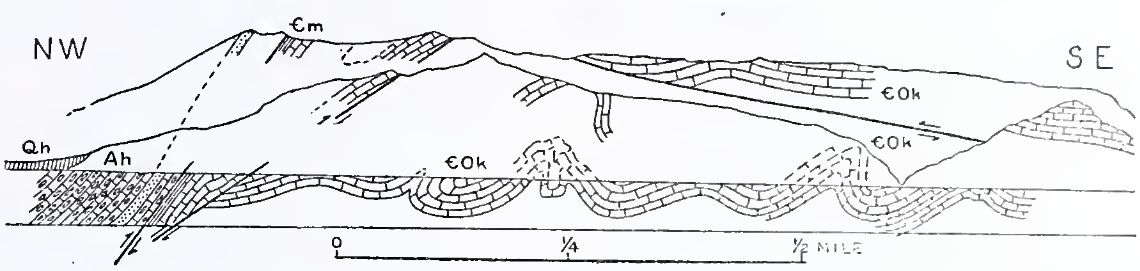


FIG. 37 (Blackwelder. Atlas sheet C I, section DD).—Section in the canyon of the Shï-t'ou-ho, east of Tóu-ts'un, Shan-si, showing Hu-t'o (Algonkian) overthrust on Man-t'o (Cambrian) shale, and Man-t'o overthrust on higher Ki-chóu (Cambro-Ordovician) limestone, from the north; also characteristic carinate folds in the Ki-chóu limestone and an overthrust within that formation from the south.

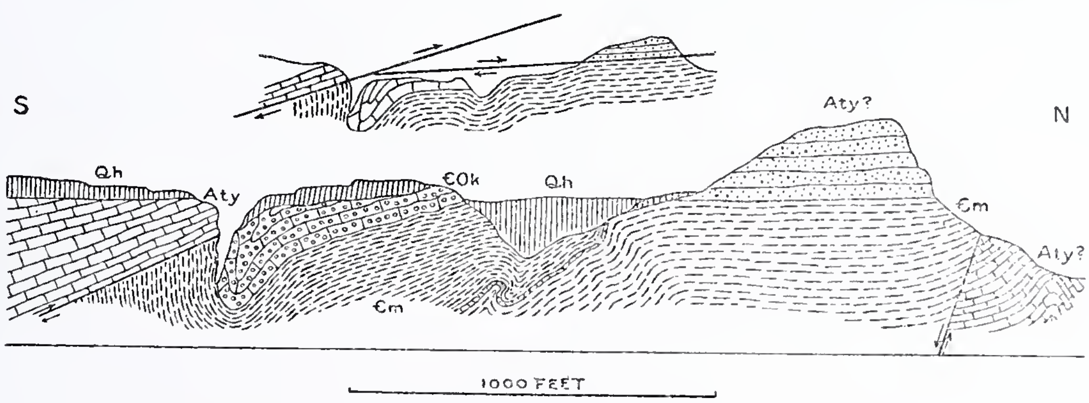


FIG. 38 (Blackwelder. Atlas sheet C I, section GG).—Wu-t'ai-hién, Shan-si. Hu-t'o (Algonkian) limestones and quartzite overthrust upon syncline of Man-t'o (Cambrian) shales.

About 10 feet, 3 meters, above the base of the limestone a few Middle Cambrian fossils were collected. Among the fragmentary remains the following species have been identified:

Coscinocyathus elvira Walcott	*Agraulos(?) melie* Walcott
Obolus obscurus Walcott	*Agraulos nitida* Walcott
(*Orthis*) *Plectorthis kichouensis* Walcott	*Agraulos uta* Walcott
Agraulos armatus Walcott	*Ptychoparia lilia* Walcott

Of these only one species was found also in Shan-tung, viz: *Obolus obscurus*, which occurs near the base of the Ch'ang-hia limestone.

In the rugged canyons of the T'ién-hua and Yau-t'óu coal district south of Wu-t'ai-hién, the Ki-chóu limestone is the prevailing formation,

its massive upper layers standing out in precipitous walls and ledges. As usual, this part of the Ki-chóu has few fossils; only scattered specimens of Orthoceras, coiled gastropods, and other forms of Ordovician age were found near the top of the limestone in the vicinity of the Yau-t'óu coal-field. In the bottoms of the valleys the thin-bedded gray and greenish limestones of the Cambrian frequently appear, giving evidence of the fact that the base of the formation is not far beneath the present grade of the river.

A few fossils of Middle Cambrian age were obtained from a horizon not more than 300 feet, 90 meters, above the Man-t'o shales:

Anomocare sp. undt.	*Anomocarella*, cf. *bura* Walcott
Anomocarella irma Walcott	

The occurrence of a trilobite closely resembling *Anomocarella bura* suggests that this is about the horizon of the top of the Ch'ang-hia limestone of Shan-tung. A southern tributary, which joins the T'ai-shan-ho south of Yau-t'óu, exposes the Man-t'o formation lying upon Wu-t'ai schists, as previously described. At the base lie 12 feet, 3.6 meters, of coarse red conglomerate and sandstone, followed by massive red shales, red limestone, and variegated sandy shales. Near the top of the formation brown shales and thin limestone are capped by the gray oolitic flags of the Middle Cambrian. At this point the Man-t'o is about 250 feet, 75 meters, thick and the oolitic portion of the Ki-chóu was estimated to comprise an additional 300 feet, 90 meters.

Vicinity of Tung-yü.—The lower members of the Sinian are admirably exposed in the hills southwest of Tung-yü (Fig. 33). They occupy the top of the ridge and lie almost horizontally upon the highly inclined Algonkian strata. The Man-t'o is represented by 170 feet, 52 meters, of red shaly rocks. At the base a variable thickness of conglomerate rests upon the slightly uneven Pre-Cambrian land surface. This is quickly followed by red shales and impure limestones, which constitute the bulk of the formation. No fossils were observed in the Man-t'o.

The Middle Cambrian rocks above the Man-t'o are gray and buff limestones, often shaly and interbedded with shales. The lower limestones contain many black oolitic bodies identical with those in the Ch'ang-hia limestones in Shan-tung. Fossils were obtained from several horizons in the oolite. Among them are many species, which have near relatives in the Ch'ang-hia limestone, and five species which are common to the two formations. Thirty feet, 9 meters, above the base of the Ki-chóu limestone the following forms were collected:

Scenella dilatatus Walcott	*Agraulos* (?) *capax* Walcott
Stenotheca (??) *simplex* Walcott	*Ptychoparia* (?) *maia* Walcott
Agraulos vicina Walcott	*Ptychoparia* sp. undt.
Agraulos (?) *melie* Walcott	

The overlying shales contain two seams of fossiliferous limestone; from the lower of these (35 feet, 10.5 meters, above the last horizon) we have:

Agraulos obscura Walcott
Ptychoparia nereis Walcott
Ptychoparia inflata Walcott
Ptychoparia vesta Walcott
Dolichometopus hyrie Walcott

The shaly horizon is overlain by a massive oolitic limestone nearly 50 feet, 15 meters, thick, and from this we obtained fossils related to the middle of the Ch'ang-hia oolite:

Orthotheca glabra Walcott
Obolus shansiensis Walcott (?)
Acrotreta shantungensis Walcott
Yorkia ? orientalis Walcott
Plectorthis sp. undt.
Agnostus chinensis Dames
Dorypyge richthofeni Dames
Dorypyge richthofeni lævis Walcott
Anomocare bigsbyi Walcott
Ptychoparia undata Walcott
Ptychoparia comus Walcott
Solenopleura pauperata Walcott
Crepicephalus damia Walcott

Above the oolite a member of the shaly limestone yielded a few additional forms:

Obolus (*Lingulepis?*) sp. undt.
Platyceras willisi Walcott
Orthotheca glabra Walcott
Dorypyge richthofeni lævis Walcott
Anomocare flava Walcott
Ptychoparia nereis Walcott
Ptychoparia sp. undt.

Near the top of the section a massive gray limestone mottled with ocher forms cliffs about 100 feet, 30 meters, high. It is very poor in fossils. The summits are composed of red, brown, and gray conglomeratic limestones, identical with those which characterize the Middle Cambrian of Shan-tung. Fossils are not abundant in them and they are represented in our collection by only two forms, both of which have close relatives in the middle Kiu-lung faunas of Shan-tung:

Agraulos regularis Walcott
Blackwelderia cilix Walcott

The conglomeratic limestone is overlain down the dip by a dense black-gray limestone, which is lithologically similar to the Ch'au-mi-tién of Shan-tung, and contains two fossils correlative with the fauna of that formation.

Plectorthis kayseri Walcott
Ptychaspis bella Walcott

From the details of this section, which is better known than any other outside of Shan-tung, it is obvious that the Cambrian rocks of Shan-si and of Shan-tung are closely similar. All the larger divisions of the one are recognizable both lithologically and faunally in the other.

In the Ki-chóu-shan.—The section just described may be considered typical of the Cambrian on the south side of the Hin-chóu basin. The bold front of the Ki-chóu-shan affords numerous opportunities to study the same strata and the fossils which they contain. Not only the Cambrian but the entire Sinian sequence, from the basal unconformity to the overlying Carboniferous, may be observed south of Ting-hiang-hién.

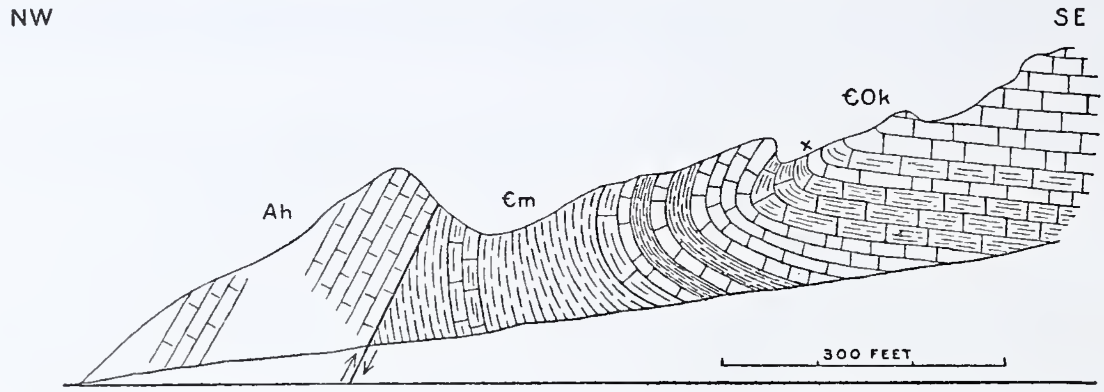


FIG. 39 (Blackwelder).—Chung-hua, Shan-si, atlas sheet B II. Lower Sinian (Cambrian) limestone and shales sharply flexed and overthrust by Pre-Cambrian limestones. (Section 0.5 mile, 1 kilometer, southwest of that represented in Fig. 31.)

South of Chung-hua the basal Sinian limestones and shales are sharply flexed and overthrust by Algonkian strata (Fig. 39); but near by, on the east, the Man-t'o red shale lies unconformably upon the older rocks (Fig. 32).

A faulted exposure (Fig. 40) of the Sinian occurs in the outlying foothills south of Han-yang. The Man-t'o and lower Ki-chóu are represented by only a small fraction of their usual thickness and are in

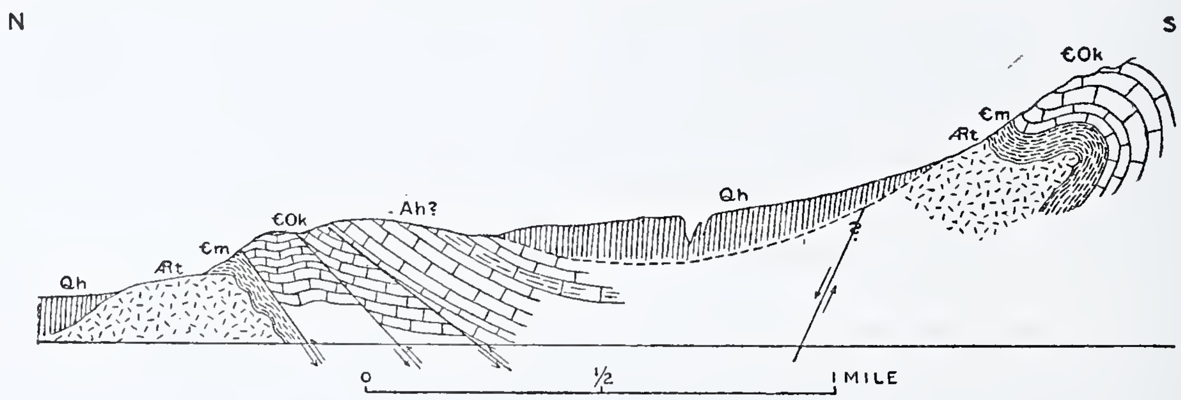


FIG. 40 (Blackwelder).—Han-yang, Shan-si, atlas sheet B II. Sinian and Hu-t'o (Algonkian) limestones in faulted succession in the foothills of the Ki-chóu-shan 4 miles, 6.5 kilometers, south-southeast of Han-yang.

turn overthrust by a dull gray saccharoidal dolomite, which is entirely unfamiliar. It bears little resemblance to the dense brownish limestone of the upper Ki-chóu, but has some features in common with members of the Tung-yü limestones farther east. We are therefore inclined to regard it as Algonkian. Pre-Cambrian red granite appears beneath the

covering of loess south of these hills. It has doubtless been brought up behind the limestones by the great normal fault of the Ki-chóu-shan.

The unfamiliar gray limestone continues westward from the Shï-ling pass an unknown distance. In the north base of these hills red shales appear beneath the loess, indicating that the overthrust of Algonkian on Cambrian persists several miles west of the pass.

PRE-SHAN-SIAN UNCONFORMITY.

In Chï-li and Shan-si.—The obscure but definite unconformity at the base of the coal-measures in Shan-tung has already been described. In Chï-li the relations are almost exactly the same.

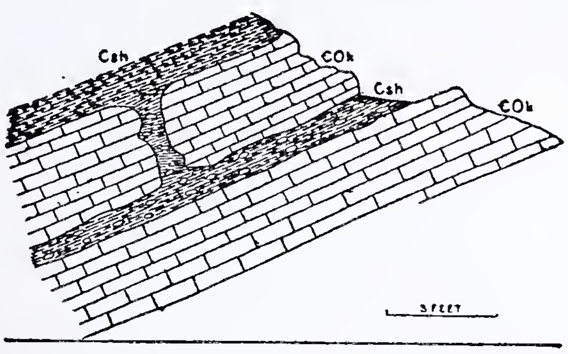


FIG. 41 (Willis).—T'ién-hua, Shan-si, atlas sheet C I. Shale at the base of the Shan-si series in joint crevices and solution cavities in Ki-chóu limestone.

At Ning-shan there are several exposures which show this unconformity clearly. The upper layers of the Sinian limestone are buff and siliceous from prolonged weathering, and the surface buried beneath the coal-measures is covered with a coarse breccia of decayed limestone rubble. The interior surface of the numerous irregular cavities, which indent the upper layers of the limestone, is rounded and coated with incrustations of silica and calcite. In these cavities, and filling the chinks in the breccia, lie shales of various colors, which are identical and continuous upward with the basal shales of the Shan-si formation. Since the shales coincide in bedding with the underlying limestones, the unconformity is not easy to recognize.

In the T'ién-hua district, Shan-si, numerous canyons expose the coal-measures and the adjacent limestones in many places, and the contact is opened by diggings for pottery clays, which are yellow and black and contain decomposed cherts. The clayey shales lie in joint crevices in the limestone, and also in solution cavities along weak layers under more massive ones, as if interbedded (see Fig. 41).

At a contact immediately above the limestone in the southern part of the field Willis observed the sequence of consolidated tufa, shale, and bog-iron ore indicated in Fig. 42. The contact with the limestone was not exposed, but occurs just below the bottom of the section on the left.

Relations similar to those noted in the T'ién-hua field were observed in the Yau-t'óu district, at the base of the Shan-si system.

The gap between the Sinian and the coal-measures represents much, if not all, of the long lapse of time from the Middle Ordovician far into

the Carboniferous period. There is no evidence that sediments of Silurian or Devonian times were deposited in any part of northeastern China which we saw.

SHAN-SI SYSTEM.

General statement.—Under the name Shan-si system we include the coal-bearing strata, which are so characteristic of central Shan-si, and also the red sandstones, which overlie the coal-measures in apparent conformity.

Isolated patches of the coal-measures occur among the mountains in western Chï-li, in synclinal troughs in the Sinian limestones. In Shan-si we found them again in detached areas south of Wu-t'ai-hién, and widely distributed around T'ai-yüan-fu, and thence southward to the mountains on the southern edge of the province. The weak shales are carved into lowlands or hills with gentle slopes; the sandstones form hills and plateaus higher than the shales and subordinate in relief to the rugged limestone mountains.

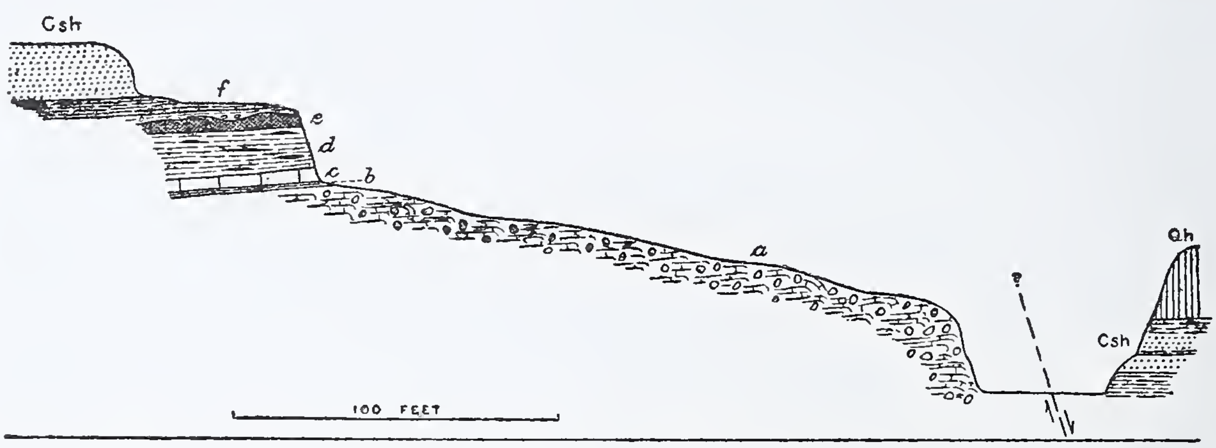


FIG. 42 (Willis).—T'ién-hua, Shan-si, atlas sheet C I. Unconformity at the base of the Shan-si coal-measures, showing surficial deposits of Carboniferous age immediately above the Ordovician limestone. *a*=limestone agglomerate, flesh-colored; pebbles up to 20 cm., matrix crystalline limestone and green shale layers; no definite bedding; structure massive; an altered superficial tufa. *b*=layer of greenish shale with limestone pebbles or concretions: 2 feet, 0.6 meters, thick; *c*= limestone, crystalline, flesh-colored, indistinctly agglomeratic; *d*=shale, dark green, calcareous, with dark red irregular layers and nodules of earthy ferruginous material, formerly bog-ore; 6 feet, 2 meters, thick; *e*= bog-iron ore, dark red, irregularly placed with gray shale; *f* = shale, very light gray, calcareous, with pebbles.

In the Ning-shan district, Chï-li.—In the mountains northwest of T'ang-hién, three small areas of the Shan-si rocks lie in the trough of a single large syncline, which strikes east-northeast to west-southwest.

Only a portion of the total thickness of the coal-measures remains, even in the Ning-shan coal-field, which is the largest of these patches; the red-brown sandstone of Shan-si is entirely absent. The coal-measures consist of variegated shales and sandstones of various colors, the sandstones being more characteristic of the upper horizons. Coal-seams are interbedded with the shales near the base of the formation. Igneous rocks were not seen.

On the T'ai-shan-ho 4 miles southwest of Shï-pan-k'óu, in the district of Wu-t'ai-hién, atlas sheet C I. View showing massive character of Cambro-Ordovician limestone, in broad syncline east of Yau-t'ou coal field. View also illustrates abrupt walls of recent canyons where they are cut in heavy limestone.

From our brief examination it is not practicable to estimate the thickness of this sequence, except to say that more than 400 feet, 120 meters, of strata are included. The unconformable relation of the underlying limestone has already been described; owing to the position of the coal-measures in the axial trough of the syncline, the upper limit of the section is an eroded land surface.

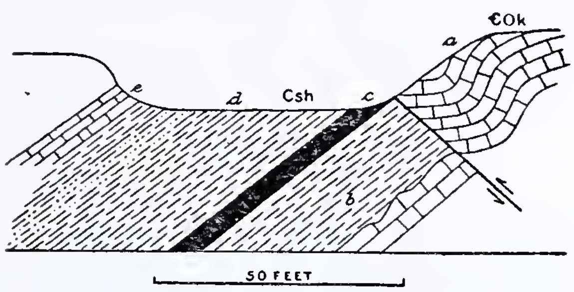


FIG. 43 (Blackwelder).—Mi-chöng, Chï-li, atlas sheet F I. Basal shales and coal-seam in the Shan-si series (Carboniferous) overthrust by Ki-chóu limestone. *a* = Ordovician limestone; *b* = dark shale; *c* = coal-seam; *d* = gray and buff shale and thin sandstone; *e* = soft gray limestone.

At Mi-chöng (atlas sheet F I) less than half of the Ning-shan coal-measures remains in a synclinal trough (Fig. 43). The only lithologic peculiarity which this section presents is the existence of a 2-foot, 0.6-meter, layer of pearl-gray marly limestone in the coal-bearing gray and buff shales. This field is cut off by a small thrust-fault, which brings the dark Sinian limestone up over the shales from the northwest.

The third exposure, west of Mi-chöng, is only a vestige in consequence of the general denudation of the region. Nothing now remains of the coal series but a few feet of the yellow and gray shales, which form the base of the formation. It is scarcely worthy of mention, except for the fact that it affords a view of the Pre-Carboniferous unconformity.

T'ién-hua-Yau-t'óu coal-field, Shan-si.—These coal-basins lie in a single syncline, which has been deeply dissected by the canyons of the T'ai-shan-ho and its tributaries. Most of the valleys penetrate into the

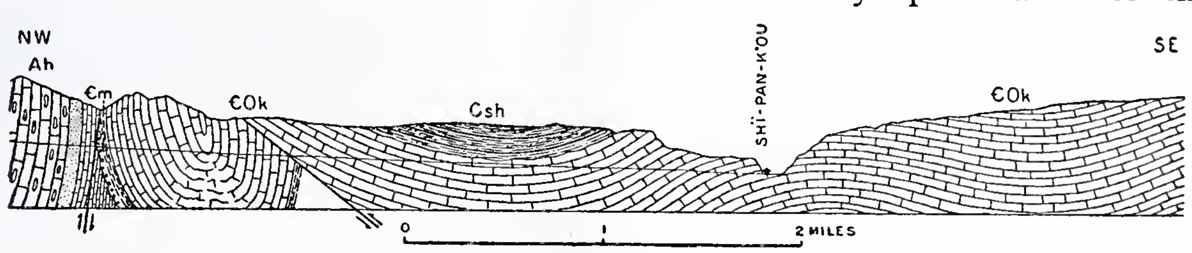


FIG. 44.—T'ién-hua, Shan-si, atlas sheet C I. Syncline of massive Sinian limestone containing a remnant of the Shan-si coal-bearing series (Carboniferous).

limestone underlying the coal-measures. The basins occupy a dissected mountain upland, bounded by higher limestone ranges to the north and south—an upland which is characterized by rounded flattish summits, rising for the most part to a common level and sloping off into deep canyons. In the Yau-t'óu basin no complete section of the Carboniferous was measured, but the stratigraphy of the T'ién-hua field, Fig. 45, is essentially similar. At the base, upon the Sinian dolomite, lie pale-yellow, gray, and brown shales, which grade upward into variegated sandstones,

sandy shales, and clay-shales with frequent bituminous layers. Coal-seams of varying thickness and purity are interspersed through this part of the series. Toward the top the formation becomes less shaly; yellowish white, and brownish sandstones alternate with thin shale beds, completing the section. The total thickness exposed is about 750 feet, 225 meters. Unlike the Shan-tung coal-fields, these north Shan-si Carboniferous terranes appear to be devoid of igneous rocks.

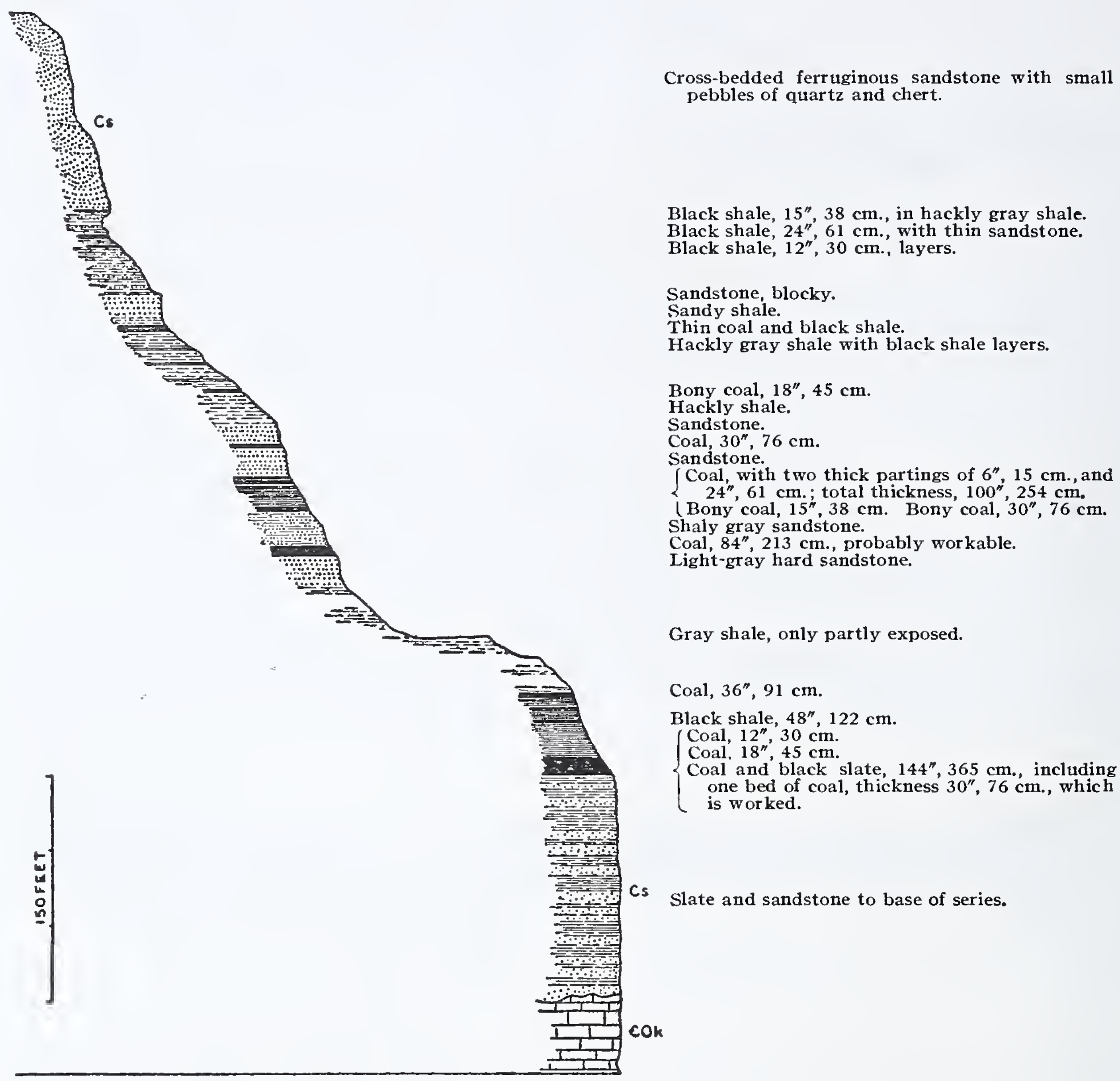


FIG. 45 (WILLIS).—SECTION OF SHAN-SI COAL-MEASURES IN T'IÉN-HUA DISTRICT, ATLAS SHEET C I.

TERTIARY.

NING-SHAN FORMATION.

Except for the Huang-t'u and river gravels, rocks later than the Shan-si series came to our notice in only one locality in the north Chï-li-Shan-si region, at Ning-shan, Chï-li. Northwest of the town, bordering the northern mountain range, is a group of low hills of rounded outlines. Their gravel-strewn slopes disclose beds of coarse conglomerate inclined gently away from the mountains. Cross-bedding is prevalent within the mass, as is evident where the material is not so coarse as to render the stratification obscure. The constituents of this rock are mostly masses of Sinian limestone, with cherts and a chert-breccia, which resembles that described from the base of the Sinian, near Nan-t'ang-meï. The pebbles, which average several centimeters in diameter and attain a maximum of over 63 centimeters, are fairly well rounded. Except where locally indurated into quartzitic layers, the rock is but weakly consolidated and weathers rather rapidly; it is harder, however, than the coal-bearing strata, and thus remains as hills while they waste away.

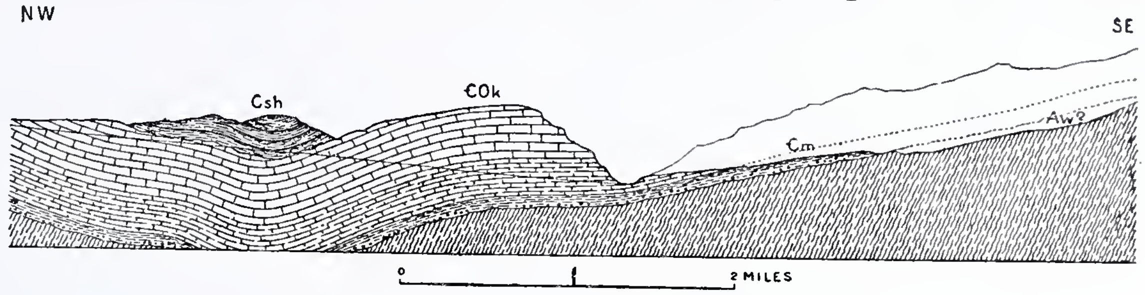


FIG. 46.—Yau-t'o district, Shan-si, atlas sheets C I and C II, section KK. Sinian formation lying unconformably upon Algonkian metamorphic rocks and preserving a synclinal remnant of the Shan-si series.

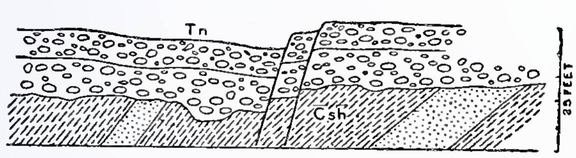


FIG. 47 (Blackwelder).—Ning-shan, Chï-li. Ning-shan gravels (Tertiary) lying upon tilted and eroded Shan-si series (Carboniferous). Post-Ning-shan faults.

The relation of these gravels to the Shan-si series is plainly visible in a bluff bordering the main road, 2 miles, 3.5 kilometers, north of Ning-shan (Fig. 47). There the yellow and red shales and white sandstone are seen tilted southward at an angle of 30°, but are truncated above by an approximately horizontal, though uneven, surface. Upon this old plain rest heavy beds of the conglomerate, with nearly horizontal stratification.

The age of the Ning-shan formation has not been determined precisely. Inasmuch as the conglomerate is separated by a considerable unconformity from the coal-measures, it is safe to say that it is Post-Carboniferous. The section which reveals the unconformity also shows

that the deposition of the gravels was subsequent to the folding and partial erosion of the Paleozoic strata. The conglomerate can hardly be older than late Mesozoic, and, judging from the slight consolidation, we are inclined to think that it may be younger. Like the Wön-ho conglomerates of Shantung, the Ning-shan gravels are intimately related in occurrence with the normal faults of the vicinity, and are probably the coarser portion of the material derived from the demolition of the fault-scarp. The scarp, as such, has disappeared entirely, and the gravels must, therefore, be set far enough back from the modern period to permit the completion of this large work of erosion after the gravels began to accumulate. Upon the basis of physiographic studies, Willis concludes that the normal faults were produced in early Tertiary time, and we therefore assign the Ning-shan formation tentatively to the Tertiary.

CHAPTER VII.

STRUCTURAL GEOLOGY OF THE NING-SHAN BASIN.

By Bailey Willis.

The Ning-shan basin is an isolated occurrence of Paleozoic rocks northwest of the city of T'ang-hién. The rocks of adjoining areas are Pre-Cambrian and consist of two series, the T'ai-shan gneissic complex, and the Ta-yang formation. The Paleozoic rocks consist of the Ki-chóu limestones, which are Cambro-Ordovician, and the Shan-si coal-bearing series, which is Carboniferous. There is also a small area of conglomerate, which is probably of late Mesozoic or Tertiary age. These strata have been described in the preceding chapter. In what follows regarding structural geology, I rely to a great extent upon Blackwelder's notes, as I was necessarily absent from the field of surveying during part of the time which we spent in the district.

The structure of the T'ai-shan complex is that of an intricate sequence of gneisses, mostly of intrusive rocks, and is of such a character that the series is with reason referred to the Archean on the strength of the structural evidence. The Ta-yang limestones overlie the T'ai-shan unconformably, and are clearly differentiated from it stratigraphically and lithologically. They belong among the latest Pre-Cambrian rocks. Gray limestones, not notably metamorphosed, though, where argillaceous, locally schistose, they are distinguished from Paleozoic limestones by the occurrence of chert in numerous layers and lenses. Although the bedding is massive, the strata are slightly folded and probably much repeated in the mountains north and northwest of Si-ta-yang. One of the best sections observed is between T'ang-hien and Nan-t'ang-meï. For 6 miles, 9.5 kilometers, northwest of Ta-yang the surface consists of gneiss, thinly and but partly covered with loess. In the banks of a small stream which flows northeast, the contact of the cherty limestone on the gneiss is exposed, and thence for a distance of 3 miles, 5 kilometers, to Nan-t'ang-meï, limestone may be seen in the mountains adjacent to the valley. The dip is in general to the northwest, usually about 25°, with some slight anticlines and synclines. Two small normal faults hading steeply to the south are seen, and the strata are traversed by a dike of quartz-porphyry. The facts as observed are indicated in the diagram, Fig. 27. At the northwestern end

of the section the highest limestone layers are overlain by a brecciated conglomerate of chert derived from the limestone, and this is succeeded by quartzite and black slate. The conglomerate marks an unconformable contact, probably between the Pre-Cambrian and the Lower Cambrian, and has been described in connection with the stratigraphy. Similar sections across the Ta-yang limestone were observed on the road which passes through the hills southeast of Ming-fu, and also west of Si-ta-yang.

Overlying the Ta-yang limestone, along its northwestern margin, occur Cambrian strata. Between Nan-t'ang-meï and Ming-fu there is an unconformable contact of deposition, showing the chert conglomerate at the base, quartzite, and then black and green argillite. Southwest of Ming-fu the contact is along an overthrust fault, which cuts out the lower members of the Cambrian and brings the Ki-chóu limestone down on to the Ta-yang limestone. They are very similar in appearance and are

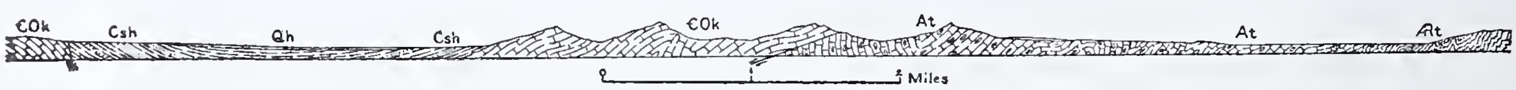


FIG. 48.—Section BB, atlas sheet F I, across the Ning-shan coal-basin, Chï-li, and the belt of Pre-Cambrian limestone southeast of it, to the T'ai-shan complex near Si-ta-yang.

FIG. 49.—Section CC, atlas sheet F I, across the Ning-shan coal-basin, Chï-li, west of Ning-shan.

distinguished only by the abundance of chert in the Ta-yang and its absence in the Ki-chóu limestone. The plane of overthrust is characterized by crushed limestone. Near Ming-fu the overthrust appears to be of slight stratigraphic throw, and probably dies out toward the northeast, but immediately southeast of Ning-shan the stratigraphic throw is greater, and much of the Ki-chóu limestone is cut out, leaving only the upper part, which closely underlies the coal-measures. The overthrust extends southwest to the Sha-ho and possibly beyond it. It thus constitutes the southeastern margin of the Paleozoic basin.

Considered in its broader features, the structure of the Paleozoics is that of a simple syncline. From the overthrust along the southeastern side, the Ki-chóu limestones dip northward at angles varying from 25° to 60°, and along the northwestern side of the basin the same strata dip southward 40° to 50°. Between these outcrops lie the Shan-si coal-measures, which, though separated from the Ki-chóu by an unconformity of erosion, are structurally seemingly conformable with the older rocks and, like them, lie in a shallow basin.

The apparently simple structure of the Paleozoics is, however, complicated by numerous folds and faults. The Ki-chóu limestones are

closely appressed and the folds overthrust toward the southeast. Overthrust faults were detected at Mi-chöng and also south of Ning-shan, and it is probable that they are quite numerous in the limestone mass. In the district northwest of Ning-shan the Carboniferous is faulted down against the Ordovician along two normal faults of moderate throw, and a third normal fault, stretching northwest of the other two but parallel to them, brings down the Ordovician in contact with the underlying T'ai-shan gneiss and forms the northwestern margin of the basin. We thus have in a small area, only about 6 miles across, close folding, overthrust faulting, and normal faulting in complex relations. Our observations do not suffice to untangle these relations in detail, but the map (atlas sheet F I) and the generalized structure sections, Figs. 48 and 49, suffice to express the broad relations.

There is one problem which remains obscure, namely, the abrupt termination of the Ning-shan basin toward the southwest. According to the strike and dip of the strata, the Paleozoic rocks should appear southwest of the Sha-ho, where we might expect that they would form high ridges as they do northeast of it; but the area in which we would look for them exhibits exposures of the T'ai-shan complex. It is evident from an inspection of the map that the overthrust fault along the southeast side of the basin gradually approaches the base of the Carboniferous rocks, cutting out the underlying Ki-chóu limestone, and it is highly probable that the Ta-yang limestone is lacking in consequence of Pre-Cambrian erosion over part of the area in which the overthrust brings the Paleozoics in abnormal contact with the T'ai-shan. It may thus occur that the Carboniferous is brought into overthrust contact with the T'ai-shan gneiss, and being eroded west of the Sha-ho, has exposed the latter below the plane of overthrust. The available facts of structure and distribution do not, however, afford a similar explanation for the abrupt termination of the high mountain range, which forms the extreme western corner of the basin, 8 miles, 13 kilometers, west by south of Ning-shan. We may infer that the Paleozoics end against a more or less complex system of overthrust or normal faults, but we have not the data by which to test the inference.

The movements which have resulted in folds and overthrusts in this district apparently belong to a single episode of compression. The folding of the Ki-chóu limestone is shared by the Carboniferous strata, and the two appear to be conformable in dip where we observed them. We are thus led to assign the episode of deformation to a post-Carboniferous time. It is in all probability to be correlated with effects of compression, observed elsewhere in the mountains of Chï-li and Shan-si as a post-Jurassic movement.

The normal faulting belongs to a later period than the folding, since the faults traverse the folds and have not been affected by them. The phenomena are very similar to the normal faulting observed in Shan-tung, and one is strongly reminded of the conditions in that province by the occurrence of conglomerates, which overlie the coal-measures in the Ning-shan basin as they do in the vicinity of Sin-t'ai, Shan-tung. There is, however, a difference, which seems to indicate that the faults near Ning-shan are the older. In Shan-tung, although the fault-scarps are eroded far back and the upthrust blocks are deeply dissected, the relief due to faulting still exists, and many masses of gneiss, which were elevated in consequence of the faulting, maintain their higher position above downthrown limestones. At Ning-shan the great normal fault along the northwestern side of the basin is no longer distinguishable as a topographic feature. On the contrary, the gneiss, which must have been raised at least 2,000 feet, 600 meters, above the Paleozoic strata northwest of Ning-shan, is now eroded to a lowland, while the limestones maintain a relatively notable altitude. The general elevation of the gneiss is now about 1,500 feet, 450 meters, above sea, whereas that in the mountain peaks of limestone reaches 2,000 feet, 600 meters. Erosion of the gneiss has thus been sufficiently rapid, as compared with that of the limestone, to completely reverse differences of altitude amounting to between 2,000 and 3,000 feet, 600 and 900 meters. This fact seems to point to a somewhat earlier inception or more rapid development of faulting at Ning-shan as compared with Shan-tung. We have seen that in Shan-tung the normal faults were probably of Eocene age, and we are thus led to assign the normal faulting at Ning-shan to the beginning of the Tertiary or possibly to the close of the Mesozoic.

CHAPTER VIII.

STRUCTURAL GEOLOGY OF THE WU-T'AI DISTRICT.

BY BAILEY WILLIS.

ENUMERATION OF DISTINCT STRUCTURES.

The following paragraphs contain a summarized statement of the general structure peculiar to each of the great series of rocks of the Wu'tai district.

STRUCTURE OF THE T'AI-SHAN COMPLEX.

Banding and contortion.—The T'ai-shan complex, which constitutes the basement of all other series of rocks observed in Chï-li and Shan-si, consists of gneisses and schists, which exhibit the internal structures due to metamorphism, igneous injection, and compression. They are minutely cleaved, are to a great extent composed of mineral particles arranged with longer axes parallel to the cleavage, and are banded in layers a few inches to a few feet thick, likewise parallel to the cleavage. The banding and nearly horizontal jointing give to mountain slopes and summits the forms which suggest stratified rocks (Fig. A, Plate XVII). The attitude of the banding frequently approaches horizontality, but steep dips and sharp contortions on a small scale are common. By exhaustive surveys, larger structures may be traced among the different varieties of gneiss and schist, but they could not be worked out in a reconnaissance.

STRUCTURE OF THE PRE-CAMBRIAN SEDIMENTS.

Schistosity and folding of the Wu-t'ai schists.—The great mass of the Wu-t'ai-shan is composed of schists, which have a general northwesterly dip. This is the attitude of the original bedding of the quartzites, marbles, and altered clayey rocks, and is also that of the schistosity. The mass is essentially isoclinal, and in general the dip is 70° to 80°, though occasionally as low as 30°. All of the rocks are highly altered, and the general development of mica-schists indicates that they recrystallized under great pressure.

The internal structure of the sedimentary masses involves both folds and overthrusts, and we have felt justified in drawing inferences regarding their occurrence in the section we observed on the T'ai-shan-ho. We recognize, however, that the inference based on only one section is liable

to be modified by broader investigation, and we have presented our deductions with appropriate qualifications in the preceding chapter. Summarizing them, we may make the general statement that certain repetitions of strata in inverse order, in connection with dips that converge downward, suggest closed synclines, while other repetitions in regular order are attributed to overthrusts.

The Shï-tsui series (see Plate XVIII) is apparently duplicated on the limbs of a syncline. The Shang-ho-miau section presents several folds which were in part observed in the field. Nan-t'ai and the southern slope of the main Wu-t'ai range consist of a partial syncline, of which the northern half is lacking. In adjacent crests of the main ridge the sequence is in part repeated in identical order, but it there includes the higher schists; and on the northern slope there is a further repetition of the same upper strata in the same order.

If our interpretation be correct, the Wu-t'ai system occurs in this section with a shingled structure (Schuppenstruktur) of which the southeastern element, the Shï-tsui series, includes the oldest strata and in which each element toward the northwest takes in higher and higher strata. A similar structure is found in the unaltered Paleozoic rocks of the southern Appalachian province.*

Folding of the Hu-t'o series.—The argillites and limestones of the Tung-yü series are sharply distinguished from the Wu-t'ai schists, in constitution and structure. They are but slightly metamorphosed and are clearly recognizable sediments. They are schistose only where their composition is that of clayey rocks especially liable to the development of cleavage or where the local conditions of pressure were exceptional. They occur in the Wu-t'ai district in a broad synclinorium, within which there are many minor folds, usually of a somewhat open character. The pitch of these folds is toward the southwest, and in accordance with this general fact it is inferred that the older strata of the series were found in the northeastern exposures, and the younger strata further southwest. If so, the lower part of the series consists chiefly of argillites and the upper of gray cherty limestones. The latter lie along the central portion of the area and the distribution of members within the basin conforms to a central synclinorium, margined by an anticlinal belt on the south and overthrust by a complexly folded belt on the north; but the minor structure is so complex and of such importance that the actual distribution is probably much more intricate. Anticlines and overthrust limbs of the lower strata no doubt appear in the area which we have mapped as composed chiefly of the limestone; and synclinal masses of the limestone no doubt occur

* See the Cleveland folio, Geological Atlas of the United States.

in the areas colored to correspond with the lower argillites. Along its southeastern margin the synclinorium is cut off by an overthrust, which constitutes the contact with the Cambrian.

STRUCTURE OF THE PALEOZOICS.

Shallow synclines and sharp anticlines.—The Paleozoic strata consist of a thin formation of shales at the base, a very thick and massive limestone sequence, and a relatively thin succession of coal-bearing sandstones and shales at the top. They constitute a very rigid strut, which is separated from the structurally distinct Pre-Cambrian rocks by the easily disturbed layer of Lower Cambrian shale. They were, therefore, capable of retaining a simple attitude over wide areas, and of moving easily upon their foundation.

The structures which the Paleozoic strata exhibit correspond with these indications. The broader areas are gentle, shallow synclines, which in this district are barely deep enough to retain small areas of the Carboniferous rocks. Associated with these synclines are sharp anticlinal folds, which frequently have vertical dips and include a keel of the Lower Cambrian shale. These anticlines are localized in consequence of the ease with which the mass moved upon its foundation, and a corresponding effect is found in certain overthrust faults, by which the massive portion of the Ki-chóu limestone comes to lie upon various older strata.

STATEMENT OF OBSERVATIONS.

Occurrences east of Tóu-ts'un.—In the high mountains east of the Shï-t'ou-ho basin, 7 miles, 11 kilometers, east of Tóu-ts'un, we first came upon Paleozoic strata in Shan-si. We there found the characteristic Lower Cambrian red shale and Middle Cambrian oolitic limestone, overturned in the northwestern limb of the syncline, as represented in Figs. 35 and 36. The northwestern boundary was marked by a zone of brecciated chert and buff limestone, later recognized as belonging to the Hu-t'o system and overthrust upon the Cambrian. The northeastern end of the syncline was traced by the occurrence of the red shales as seen from the ridge, but we were unable to extend our observations by descending the wild canyon in the mountains further east. As our route up the T'ai-shan-ho, across Pre-Cambrian schists, was but 5 or 6 miles, 8 or 10 kilometers, northeast of the great synclinorium in which the Paleozoic strata lie, it is evident that the latter do not extend far in that direction. The rising pitch of the axis carries them out to the mountain summits.

The canyon of the Shï-t'ou-ho, southeast of Tóu-ts'un, exposes the section shown in Fig. 37. At its northwestern end limestone and quartzite

of the Tung-yü series lie upon red shale and oolitic limestone of the Cambrian in inverted order, the Pre-Cambrian being overthrust along the stratum of easy movement, the Lower Cambrian red shale. About 800 feet, 240 meters, further downstream the thin-bedded oolitic limestones are overthrust upon the very massive Ki-chóu (Cambro-Ordovician) limestone which normally overlies them, and this massive limestone forms the section for 2 miles, 3.5 kilometers, further to the southeast, as far as it was followed. Later observations southeast of Shï-p'an-k'óu show that the synclinorium is about 6 miles, 10 kilometers, wide. In general the dips are gentle, though variable, but there are two conspicuous keel-shaped anticlines overturned southward, and also rectangular folds.

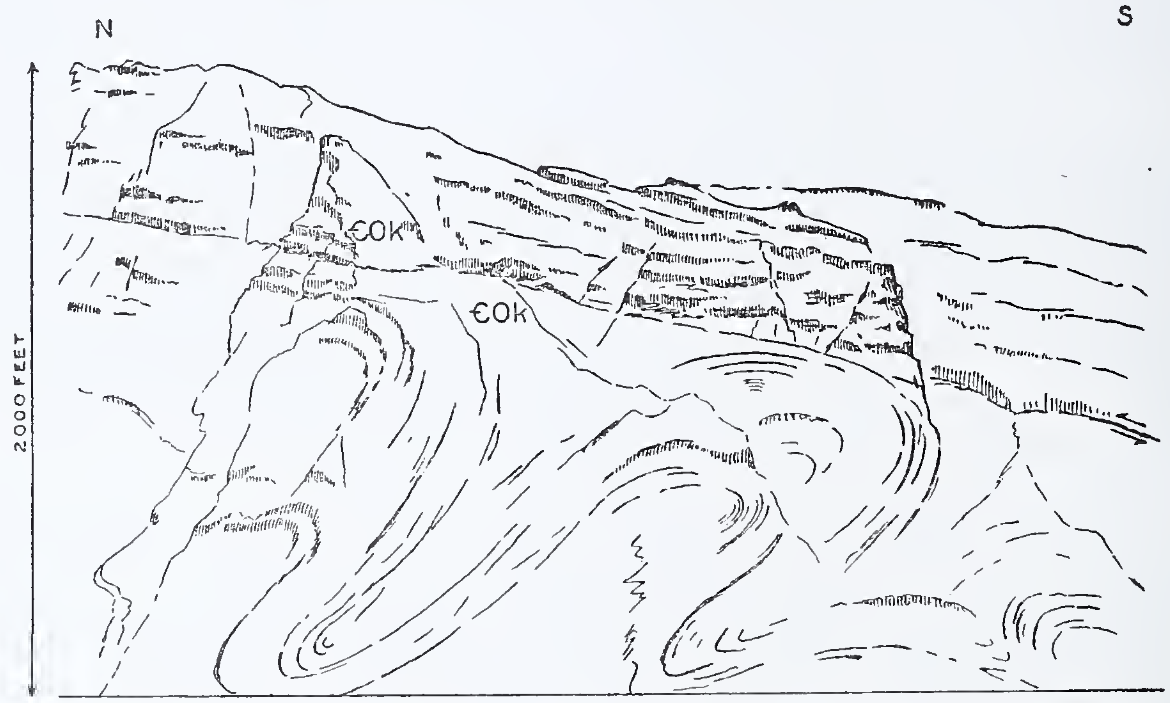


FIG. 50 (Willis).—Wu-t'ai-hién, Shan-si. In the canyon of the Sing-ho, 7 miles, 11 kilometers, southeast of the city. Sketch of canyon wall showing the Ki-chóu limestone closely folded and overturned southward, and overthrust by a massive plate of the same formation.

Section on the Sing-ho.—Southeast of Wu-t'ai-hién the narrow canyon by which the Sing-ho escapes from the broad basin exposes a section of unusual interest. Near the northern end of the canyon, on the southwestern bank, is an isolated hill which rises 210 feet, 700 meters, above the river. Its complex structure is delineated in Fig. 38. It consists of dark red Man-t'o (Cambrian) shale, capped by quartzite of the Hu-t'o system. Along its southern slope oolitic limestone and red shale occur in a synclinal fold. Outcrops of the red shale are distinguishable on the eastern slope of the canyon, and the stratum, together with the oolite, is continuous and widens to beyond the Shï-t'ou-ho. At the Sing-ho the syncline is pinched and ends. The vertical southern limb of red shale,

which is exposed in a remarkably narrow gorge, is overridden by a body of red-brown earthy limestone of the Hu-t'o system, dipping gently southward. The contact is one of overthrust from the south, that is, from a direction opposed to that of overthrusts previously observed. Further down the canyon of the Sing-ho, beyond an interval covered by Huang-t'u, we observed argillites and thin-bedded limestones of the Hu-t'o dipping 60° to 70° south, and still further beyond we came upon the Ki-chóu limestone. We ascended the ridge southwest of the river, and proceeding along it, observed the structure of the limestone in the eastern canyon wall. It is sketched in Fig. 50, which represents a section about 1,200 feet, 350 meters, high and half a mile long. The broad mountain surface is composed of a flat plate of the upper massive Ki-chóu limestone; but underneath are similar limestone strata, closely compressed in carinate folds and overturned southward; between the two is a plane of dislocation. The structure exhibits two bodies of strata thrust in opposite directions, the one under, the other over.

The structure of the lower limestone mass corresponds with that of the Ki-chóu in the Shï-t'ou-ho section, and the overthrust plate is that which carries the coal-basins of the Tién-hua and Yau-t'óu fields. The thrust was observed northeast of T'ién-hua, but was not traced further east, though it probably extends beyond the Shï-t'ou-ho. Toward the southwest, between the Sing-ho and the Hu-t'o-ho, the Ki-chóu limestone covers a large area, and along an extension of this fault-plane is probably overthrust upon the Hu-t'o gray limestones; but the two series are so similar that we failed to distinguish the contact.

Section on the Hu-t'o-ho.—The section on the Hu-t'o-ho south of Tung-yü and through the Yau-t'óu coal-field is simple. The Sinian system lies in a syncline. Along the northern margin is the unconformable, but undisturbed, contact with the Hu-t'o system. Along the southern, beyond the T'ai-shan-ho, is an anticline from which the Sinian dips 18° northwest, and which is high enough to bring up the Pre-Cambrian above the canyon bottoms, though the mountain summits for some miles further southeast appear to consist of massive limestone.

In this broad and shallow syncline there are three remnants of the Shan-si coal-bearing series. The eastern or T'ién-hua basin is cut in two by the brook which crosses it. The greatest depth of the basin, corresponding to the greatest thickness of coal-measures, is about 700 feet, 210 meters. The area of the Carboniferous strata is 2.5 miles, 4 kilometers, long by 1 mile, 1.6 kilometers, wide (Fig. 44). The Yau-t'óu field is likewise a simple syncline about 6 miles, 9.5 kilometers, long and a mile wide. It is cut to a depth of 100 feet, 300 meters, nearly to the bottom of the coal-measures, and is thus completely drained (Fig. 46). The third

area is much smaller. It lies in the high range south of Chung-hua, and according to native accounts contains very little coal.

North of the principal syncline on the Hu-t'o-ho, on the west side of the river, occurs a detached remnant of the Sinian. It forms the greater part of the ridge southwest of Tung-yü. The strata dip gently south. They lie unconformably upon the steeply dipping Tung-yü argillite and limestone, extend under the river level, and should be continuous with the same strata in the syncline to the south; but they are traversed by a normal fault, with downthrow to the north, which occasions the repetition of the red shale and oolitic limestones.

Section in the Ki-chóu-shan.—In the lofty mountain range which rises southeast of the Hin-chóu basin, Sinian strata form the summit and a greater part of the northwestern slope. The structure is complex and our observations did not suffice to trace it out in detail. Immediately

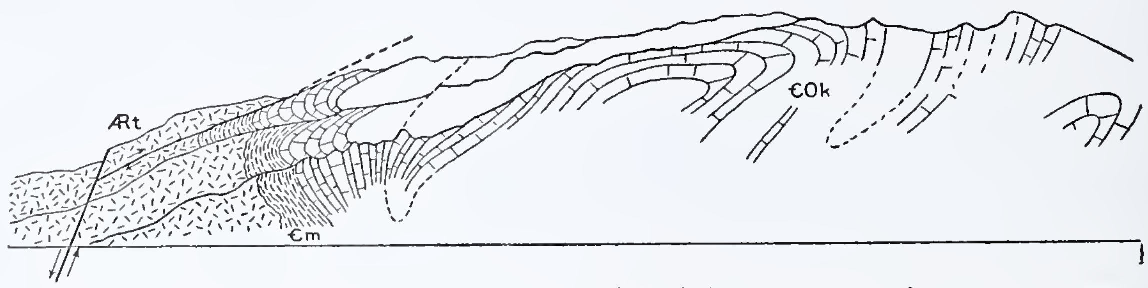


Fig. 51 (Blackwelder).—Ki-chóu-shan, Shan-si. View of the western end of the range, as seen from the slope below the triangulation station south of Han-yang; showing the Sinian system bent in closed folds and overthrust from the north by Pre-Cambrian granite.

southeast of Chung-hua the red shales at the base of the series occur in the lowest foothills, in a nearly vertical or overturned attitude; they are overthrust from the north by Hu-t'o strata, and on the southeast are succeeded by overlying limestones in a sharply compressed syncline. Near the crest of the range, 1 mile, 1.5 kilometers, further southeast, is an anticlinal axis in the limestones, and southeast of the summit occurs a syncline in which coal is mined (Figs. 39 and 51).

The trend of the flexures is more to the west of south than that of the normal fault-scarp, and therefore the anticlines and synclines run out successively into the face of the range, and are cut off.

About 3 miles, 5 kilometers, east-southeast of Han-yang, an overthrust, which is believed to be nearly parallel to these folds and is known to be older than the normal fault, brings the Pre-Cambrian granite over the Man-t'o shale from the north. The trenching of the gently inclined fault-plane has caused the lower Sinian strata to appear in the bottoms of the gulches, while the granite remains in the ridges which separate the small valleys (see Fig. 31).

Near the western end of the Ki-chóu-shan the folding appears to have been especially complex (see Fig. 51). At the north base of the range,

near its western end, the granite appears from under the Huang-t'u, rises high up on the slope in an anticline which is slightly overturned toward the south, and then sinks gradually to lower altitudes northeastward.

Isolated hills east and north of the Shï-ling.—The little hill immediately adjacent to the Shï-ling is composed of typical upper Ki-chóu limestone containing a few characteristic fossils. The dips of this hill are southward on the south side of it, and northwest on the west side, indicating part of a pitching anticline, which is perhaps continuous with one of those in the mountain immediately east of it.

The structure in the two rocky hills between Han-yang and Shï-ling is not simple. Several thrusts from the southeast cut out the greater part of the Man-t'o and Ki-chóu formations, and cause them to be overlaid by an unfamiliar dark limestone, which is believed to be a member of the Hu-t'o system. North of this limestone another thrust brings up the granite, but the fault was not observed on account of the covering of loess.

The smaller castellated hill further west is equally complex, and closely related to the one just described. In the north base a remnant of the Man-t'o shale is followed by a small portion of Ki-chóu limestone, the crest and north slope being composed of the dark limestone, which is supposed to be part of the Hu-t'o.

Vicinity of the Shï-ling.—West of the Shï-ling a dark granular limestone of the Hu-t'o system forms the greater part of the ridge and dips gently south-southeastward. It is the same as that seen in the isolated hills which have just been described, and is no doubt in the strike of that structure.

The hills further west and northwest, through which the Mu-ma-ho runs, consist of Pre-Cambrian granite and gneiss.

The southwestern extension of the Ki-chóu-shan, beyond the Shï-ling, sinks beneath the plain of Huang-t'u, but reappears again in the hills and plateau mapped in the southwestern part of atlas sheet B II. The detailed structures of the range do not persist, but the Cambro-Ordovician rocks range southwestward on the southeastern side of the belt of Pre-Cambrian rocks, which represent the great anticlinorium of the Wu-t'ai-shan. As is stated in the chapter on the structure of Central Shan-si, this anticlinorium probably extends southwestward many miles and passes west of Fön-chóu-fu.

Normal Faulting.

Ki-chóu-shan fault.—Normal faults are rare in the Wu-t'ai district, so rare that we discovered but one of notable character. This one, however, is a fault of great magnitude, and is the northeastern representative of a great line of fractures, which extend southwestward entirely through the province of Shan-si. Its appearance south of Tung-yü, where it interrupts the continuity of the Sinian strata, has already been referred to. We

did not actually see the fault at this point, but the dislocation of the strata was observed from the hills east of the Hu-t'o-ho, north of the Yau-t'óu coal-field. It is especially marked by the repetition of the red shales at the base of the Sinian. Still further southwestward, along the base of the Ki-chóu-shan, the evidence of faulting is seen in the depression of the floor of the Hin-chóu basin, the elevation of the crest of the range to an altitude of 3,000 feet, 900 meters, above the plain, and the steep scarp of the range. The details of topographic features are discussed under physiography, but we may here note that the mountain front extends, in a slightly convex continuous face, for a distance of 20 miles, 32 kilometers, without prominent spurs. Its surface is gashed by ravines, but not yet deeply dissected, and along that portion of its extent where alluvial cones have not developed to great height the short spurs end toward the plain in triangular facets, which fall into a common plane, are vertically grooved, and are taken to represent the actual plane of dislocation. The displacement on this normal fault is apparently greatest immediately southeast of Chung-hua, where it amounts to the height of the range above the plain, 4,000 feet, 1,200 meters, plus an unknown amount below the plain. From this maximum the displacement diminishes rapidly, both northeastward and southwestward, and the fault apparently dies out in 15 or 20 kilometers.

DATES OF EPISODES OF DEFORMATION.

PRE-CAMBRIAN EPISODES.

Post-Wu-t'ai deformation.—Being sedimentary strata, the Wu-t'ai schists were originally deposited in a nearly flat attitude, with a simply bedded internal structure. They are now complexly folded and schistose. The changes of form are of an intense and universal character, and are accompanied by equally general changes of constitution, inasmuch as all the mineral constituents have been recrystallized and have entered into new combinations. This universal alteration is not shared by strata of the succeeding Hu-t'o series, and must, accordingly, have taken place before the latter were deposited. After the shales, limestones, and sandstones of the Wu-t'ai system had been deposited, they were buried till they reached a position favorable to recrystallization and the development of cleavage, and were elevated and eroded before the Hu-t'o epoch began.

Post-Hu-t'o deformation.—Although, southeast of Tóu-ts'un, Hu-t'o strata occur locally along a thrust-fault in apparent conformity with the overturned Cambrian, the two series were elsewhere found in marked unconformity of sedimentation and dip. At the undisturbed contact southwest of Tung-yü the Sinian is nearly horizontal and the Tung-yü nearly vertical. The evidence of general sections is, moreover, confirmed by the general distribution, as the Sinian overlaps upon different members

of the Hu-t'o system, in complete unconformity. There is, therefore, no doubt that, after deposition of the Hu-t'o strata and before the invasion of the Cambrian sea, there ensued an episode of folding, which intensified the deformation of the Wu-t'ai schists and threw the Hu-t'o beds into open synclinal and anticlinal folds.

PALEOZOIC INTERVAL.

Movement without compression.—After the deformation of the Hu-t'o system in Pre-Cambrian time, there ensued an episode of erosion and marine planation, which resulted in a practically flat surface. In consequence of subsidence the area was covered during Cambrian and Ordovician time to a depth of about 3,000 feet, 900 meters, with limestone strata of uniform character and great extent, and possibly by other beds of moderate thickness, representing more or less of the Middle Paleozoic. Before the advent of the Upper Carboniferous, these strata were elevated apparently as uniformly as they had previously subsided, and the surface of the youngest limestone suffered more or less erosion. Upon this surface, in late Carboniferous time, were deposited a few hundred feet of coal-measures. Throughout these movements of elevation and depression, which occupied the whole of the Paleozoic and an interval of unknown duration in the Pre-Cambrian, the region was free from compressive stress of sufficient intensity to deform the rocks.

MESOZOIC DEFORMATION.

Episode of folding.—Upper Carboniferous strata are folded with the earlier Paleozoic rocks, in the synclines of T'ién-hua and Yau-t'óu (atlas sheets C I and C II), and the epoch of folding is thus placed at a later date. It is not possible in the absence of younger strata in this district to say positively how much later, especially as the evidence for other regions where such rocks occur is contradictory.

In Shan-tung, the late Paleozoic strata, probably including Permian, appear to be folded with Jurassic beds. In the middle Yang-tzï region we observed apparent conformity between the folded Carboniferous and the K'ui-chóu (Permo-Mesozoic), of which the upper part is apparently late Triassic.* Thus, on the evidence of these two widely separated regions, between which the Wu-t'ai district occurs, we should assign the date of folding to a post-Triassic time. Observations in regard to the apparent conformity of the Jurassic or Triassic with the Permian and Carboniferous are not, however, conclusive; in Shan-tung the latest Carboniferous or post-Carboniferous strata are but slightly flexed, are associated with contemporaneous volcanics, and are much faulted; their relation to the Jurassic is, therefore, not clear. And in Ssï-ch'uan, 200 miles, 300 kilometers, west of our route, the Permo-Mesozoic of the Red Basin lies

*Chapter XIII.

unconformably upon folded, deeply eroded, and planed-off Paleozoics.* Moreover, the Triassic or Jurassic age of the higher strata rests upon the evidence of incomplete collections of fossil plants, from a district where the evolution of floras during the late Paleozoic and Mesozoic was peculiar† as compared with Europe and America. It follows from these qualifications, that we can not with confidence place the episode of folding in the Wu-t'ai district more nearly than to say that it was probably Mesozoic. In the chapter on the middle Yang-tzï region we consider the possibility of two episodes, the one during the Triassic, the other post-Jurassic.

TERTIARY MOVEMENTS.

Warping.—Even although we should extend our search far beyond the limits of the area under consideration, we would find no Tertiary sediments. There is no evidence of a submergence later than the Paleozoic, although there are continental deposits of Jurassic age near Ta-tung-fu. As an area of erosion, northwestern China ultimately reached a peneplain condition, which characterized the landscape in early or middle Tertiary, during what we designate the Peï-t'ai cycle,‡ and it is evident that the net result of the movements following the Mesozoic epoch of folding was perhaps a certain amount of warping, ending in quiescence and advanced erosion. Early in the Tertiary occurred the normal faulting, which is represented in the Ning-shan basin of Chï-li and in Shan-tung. Late in Tertiary time there began certain broad movements, which resulted in elevation and depression, but it was not until the late Pliocene that marked deformation took place; and not until the middle of the Pleistocene, as we interpret the facts, that the very pronounced features of the mountain chains were initiated. Deformation then assumed the form of normal faulting.

QUATERNARY MOVEMENTS.

Normal faults.—Normal faulting constitutes a feature of the structure which is distinct in type and time from all other features. It has no relation to the folds of the rocks, which it transects at an acute angle in the face of the Ki-chóu-shan, and being an effect of vertical warping is in strong contrast to the results of tangential thrust. The folding probably ceased in the Mesozoic, but the faulting, begun in this region not earlier than the Pleistocene, has continued almost or quite down to the present.

One great normal fault occurs in the Wu-t'ai district, stretching along the base of the Ki-chóu-shan, between the mountain mass and the sunken floor of the Hin-chóu basin. It is a feature of the great fault system of central Shan-si, and as such is described in the next chapter.

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*Von Richthofen, China, vol. II, p. 602.

†White's report on Plants from the K'ui-chóu Series, Chapter XII.

‡See Chapter XI.

CHAPTER IX.

OBSERVATIONS IN CENTRAL SHAN-SI.

STRATIGRAPHY.

By Eliot Blackwelder.

INTRODUCTION.

The formations which we found along our route of travel through Shan-si to Shen-si are essentially the same as those described in the preceding account of the district north of T'ai-yüan-fu. The Pre-Cambrian rocks represented belong to two and possibly to three systems. They are followed by the Sinian and Shan-si systems of the Paleozoic, and over all is distributed the Huang-t'u formation. As it was not practicable to make detailed observations in the course of this rapid journey, the construction of a continuous section is not attempted.

THE PRE-CAMBRIAN.

Pre-Cambrian rocks occur in almost all of the higher mountains visible from the imperial highway. The existence of a somewhat extensive exposure to the west of T'ai-yüan-fu is indicated by the composition of the gravel, which is brought down to the plain by the Wön-shui-ho. In addition to the reddish sandstones and Sinian limestones which occur in the hills bordering the plain, this material comprises black-and-white hornblende-granite, coarse pink granite, hornblende-porphyry, basaltic rocks, and quartzites of various colors. These rocks are presumed to come from a rugged range of mountains, which is visible from the mouth of the Wön-shui valley and appears to be 12 to 15 miles, 19 to 24 kilometers, distant toward the north. The rocks indicate the occurrence of the T'ai-shan complex and one or more of the Pre-Cambrian sedimentary series.

About 5 miles, 8 kilometers, west of Wön-shui-hién, the monoclinal fold, which raises the entire Sinian system up from under the prevailing coal-measures, exposes beneath the Cambrian a system of rocks, which develops irregular hills of rounded contour. As seen from a distance, these hills are dark in color in contrast with the light buff tinge which is characteristic of exposures of the basal complex. Topography and color suggest the dark limestones and slates of the Hu-t'o system, but Obrutschov, who passed nearer the hills, mentions only gneiss and granite as lying beneath the Cambrian.

East of the road, in the central portion of the province, rises the precipitous range called the Ho-shan. Its lower slopes, and in places the entire mass, appear from a distance of 10 miles, 16 kilometers, to be composed of dark metamorphic rocks, highly inclined but without notable differences in hardness. Near the base of the mountain one sees limited exposures which are much lighter in color; it is probable that these are outcrops of the basal complex. As a check on these distant observations, we have the material brought down by the streams which rise on the slopes of the Ho-shan. The tributary which enters the Fön-ho at Ling-shï-hién brings down pebbles of quartzite, hard gray limestone, and gray gneiss and pink granite in subordinate amounts. The next stream of importance to the southward, near Yön-yi-ssï, furnishes quartzite and limestone, but apparently not the gneiss and granite. Another stream, which rises near the south end of the range and passes by Chau-chöng-hién, carries gneiss, granite, diorite, a large amount of quartzite, and a little gray limestone. The existence, in the Ho-shan, of the basal igneous complex and one or more of the metamorphic sedimentary systems is thus indicated. The gray limestones, as will be mentioned later, probably belong to the Sinian system.

Northeast of Kiang-chóu a short range of mountains rises through the prevailing Huang-t'u. Stratified rocks appear on its northern side, dipping northward, a rounded cliffless exposure indicating rocks of nearly uniform resistance to weathering. Beneath them, and forming the larger portion of the mountain, are massive light-colored rocks which are probably part of the basal complex. The aspect of the sedimentary rocks just mentioned agrees most closely with the limestones of the Hu-t'o system near Wu-t'ai-hién.

A few miles to the southeast of Kiang-chóu a low rounded spur extends westward almost to the main road. The topography suggests folded limestones or quartzites associated with softer massive rocks. This suggestion is partially substantiated by the material found in the bed of a ravine which heads in the edge of this spur; the pebbles consist of granite, diorite, and a large amount of quartzite. In this instance limestone seems to be altogether absent.

From the great range of the Föng-huang-shan, in the extreme southern part of the province of Shan-si, von Richthofen reports gneiss and crystalline schists overlain by reddish quartz-sandstone.* We did not make an examination of the mountain, and it was even hidden from our view by clouds much of the time while we were passing; but what we saw of its topography showed that the mountain was principally made up of massive rocks, in which no definite structure was visible at a distance. At the

*China, vol. II, page 450.

extreme west of the range we had an opportunity, for the first time, to examine the material from it, which consisted of granite, gneiss, and basic intrusive rocks, without quartzites or limestones. This would indicate that the western end of the range, at least, exposes nothing but the basal complex. The quartzitic sandstone seen by von Richthofen resembles certain members of the Hu-t'o system to the northward, and is thought to be of Pre-Cambrian age.

The front of the great range which extends from Tung-kuan westward, almost to Si-an-fu in Shen-si, and of which the Ta-hua-shan is the chief height, appears to consist wholly of the gneissic complex. This impression was derived in the first place from the rugged irregular forms of the mountains. The Hua-shan itself seems to be composed of massive granite, in which joints are widely spaced and are at least partly vertical. Detrital material from the front of this range consists almost entirely of a variety of gneisses, granites, and other igneous rocks. The only exposure of the bed-rock which we examined is that at Lin-tung; there it proved to be a gray gneiss.

PALEOZOIC.

Sinian System.

Like the preceding systems, the Sinian rocks are almost confined to the mountain groups. We did not see them along our route of travel in Shan-si south of the latitude of Ho-chóu. Stratified rocks of unknown character do, however, occur at high altitudes in the central portion of the Föng-huang-shan, and it is not unlikely that these may prove to be Sinian limestones.

On the west side of the valley, between T'ai-yüan-fu and Tsin-tzï-chön, the upper part of the Ki-chóu (Cambro-Ordovician) limestone is exposed beneath the coal-measures. At Tsin-tzï-chön the limestones descend beneath the surface with a southwesterly dip, and do not reappear until brought up again by the monoclinal fold just west of Wön-shui-hién, where the entire Sinian sequence is probably exposed.

In the mountain immediately east of Kié-hiu-hién, a part or all of the Sinian is brought up by a normal fault, provided our inferences as to the structure here are correct. In this place the base is apparently not visible.

The Sinian makes just one appearance on the great road itself; at Ling-shï-hién a broad anticline raises the uppermost 100 to 200 feet, 30 to 60 meters, of the Ki-chóu limestone into view beneath the coal-measures. The rock is a dense, dark-brown limestone of irregular fracture, resembling in all its details the Ordovician limestone, which is so wide-spread throughout northern China.

In the crest of the Ho-shan, already mentioned, stratified rocks may be seen lying with a very gentle dip toward the east. In the contour and succession of the cliffs and gentle benches, they resemble the Sinian formation as developed further northward. The lowest member is evidently soft, and a reddish color can be detected in it with a field-glass. From this we infer that this member is the Man-t'o shale formation. As additional evidence that the Ho-shan contains Sinian limestones, it should be mentioned that the float brought down by the streams includes dense gray limestones of the types which are characteristic of the Ki-chóu group.

Shan-si Series.

From the explorations of von Richthofen* and other observers, it is known that the Carboniferous and Permo-Carboniferous continental deposits are broadly exposed in the province of Shan-si. We propose the name Shan-si series accordingly. We found them frequently from the vicinity of T'ai-yüan-fu southward to the westward bend of the Fön-ho. Between T'ai-yüan-fu and Wön-shui-hién the exposures are almost continuous. There are two prominent terranes: (1) the soft shales of varied colors which von Richthofen called Tai-yang, which contain the coal-seams and lie directly upon the Sinian limestone; and (2) a thick sequence of light reddish sandstones with subordinate amount of sandy shales. The former are upper Carboniferous; the latter have been referred to by von Richthofen as "Ueber-carbon."

Between Kié-hiu-hién and Chau-chöng, wherever the Huang-t'u has been removed, the Shan-si series is exposed. Throughout this portion of the district the red sandstones appear to have been eroded, as we find only the lower member, which consists of greenish, yellow, brown, and black shales and earthy sandstones; coal-seams are reported to be numerous. Immediately north of Yön-yi-ssï a local bituminous limestone is interbedded with the shales; it is about 30 feet, 9 meters, thick, is quite hard, and contains well-known Upper Carboniferous fossils. The specimens collected comprise: *Chonetes* sp. aff. *C. Flemingi; Hemiptychina* sp. aff. *H. orientalis; Ostracoda* indet.

The great thickness and persistence of the mantle of Huang-t'u from Chau-chöng southward prevents observations of the underlying coal-measures. A few miles south of Ho-ma-chön there are exposures in the roadway of an earthy greenish sandstone which is believed to be a part of the Shan-si series.

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*China, vol. II, pp. 399–477.

STRUCTURAL GEOLOGY.

By Bailey Willis.

General Relations.

The structure of central Shan-si is closely linked with that of the Wu-t'ai district, which has already been described in detail. The general trend of the axes of folds extends southwestward from the Wu-t'ai-hién basin, northwest of T'ai-yüan-fu and Fön-chóu-fu; and the normal fault of the Ki-chóu-shan is represented further south, by the system of faults which give rise to the Ho-shan, the Fön-huang-shan, the Ta-hua-shan, and the Ts'ing-ling-shan, a system which extends 450 miles, from latitude 34° and longitude 108° in the province of Shan-si, to latitude 38° 30′, longitude 113° in Shen-si. The fault system is associated with smaller or larger downwarps, which constitute the loess basins of Tóu-ts'un, Wu-t'ai-hién, Hin-chóu, T'ai-yüan-fu, P'ing-yang-fu, Kié-chóu, and the Weï valley.

The folding of the Pre-Cambrian and Paleozoic rocks is a structure developed by compression probably during early or middle Mesozoic time. The normal faulting and warping are features of Quaternary origin, which result from vertical movements. We thus have exemplified here two great classes of structure, strongly distinguished in character and in time of development. The folding has been described in accordance with our detailed observations en route between Pau-ting-fu and T'ai-yüan-fu; and in our rapid journey between T'ai-yüan-fu and Si-an-fu we added nothing beyond the general recognition of the existence of similar structures in rocks of like age throughout Shan-si and Shen-si. Our contribution to knowledge of these facts is therefore limited, though it embodies some corrections of the notes of von Richthofen, as published in "China."* Our observations on the normal faulting and warping were made from the point of view of physiographic studies as well as structural studies, and a full discussion of them involves taking account of the physiographic aspects. This section is limited to their strictly structural aspects.

PRE-CAMBRIAN AND PALEOZOIC.

Observations En Route.

The highway from T'ai-yüan-fu to Fön-chóu-fu, a distance of 55 miles, 88 kilometers, in direct line, lies along the northwestern margin of the plain of the T'ai-yüan basin, much of the way close to the foothills, but between Wön-shui-hién and Fön-chóu-fu at a distance of several miles from them. The route has been traveled by von Richthofen,

*China, vol. II, chapter IX, pp. 399 *et seq.*

Obrutschov, and ourselves, and similar observations have been made in passing, but interpretations are not always the same. The route approaches the hills from T'ai-yüan-fu in the vicinity of T'ai-yüan-hién, and reaches the town of Tsin-tzï-chön, which is particularly attractive because of the large springs there flowing from the limestone. The rock is the limestone of the upper part of the Sinian system, which is here brought up on an anticline in which the strata dip 5° northeast and 20° southwest. The arch is sufficiently broad and high to raise the limestone above the level of the plain for several miles and to throw the outcrop of the overlying coal-measures back into the range. From Tsin-tzï-chön to Kiau-chöng-hién the coal-measures form the face of the range, but exhibit undulations which constitute two major synclines with an intermediate anticline. From Kiau-chöng-hién to Wön-shui-hién the red sandstones above the coal-

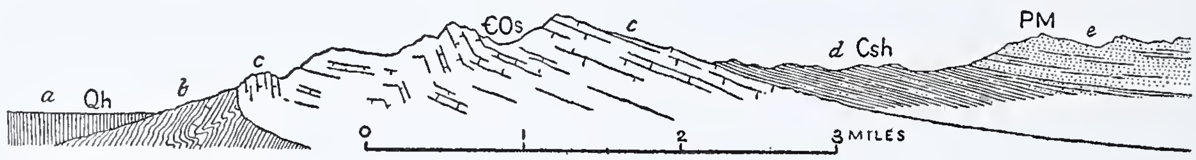


FIG. 52 (Willis).—Wön-shui-hién, Shan-si. Diagrammatic section of the Sinian in the Shï-hia-shan, as seen from the main road together with inferred relation to the Shan-si coal-measures and later strata. *a* = basin of Fön-chóu-fu filled with Huang-t'u (Qh); *b* = lower slopes, probably of Pre-Cambrian strata; *cc* = limestones of Sinian system; *d* = Shan-si coal-measures; *e* = post-Carboniferous sandstones, probably Permo-Mesozoic.

measures constitute the surface in a nearly flat attitude, and coal-bearing strata sink deeper in the corresponding broad syncline. This syncline is bounded on the west by a high range of mountains, the Shï-hia-shan*, which extends from the plain in a direction north by east. We were told that along its southeastern base there is a valley in which coal is extensively mined—that is to say, there is in the valley the outcrop of the western limb of the wide syncline whose eastern side is near Kiau-chöng. The main mass of the range is composed of Sinian limestones which exhibit step-like folding, the strata being alternately nearly vertical and nearly horizontal (Fig. 52).

The range is described by von Richthofen as follows:

On the way to the great city of Wön-shui-hién one sees the escarpment of the plateau overtowered by a rugged mountain range, which rises at least 2,500 feet above the plain. One soon obtains the full view from the south. In sharp contrast to the horizontal stratification of the varicolored rocks of the plateau, one sees a massive system of limestones, which look dark, but which betray their real color in the yellow fracture planes, and which rise with steep dip from the valley. One is inclined to take this for a much older mountain system, but further observation does not justify this hypothesis. The range of the mountains from northeast to southwest comes to an end. The plain extends in a wide embayment toward the west. As the highway trends diagonally across the embayment I could see the forms of the mountain slope in its westward continuation only from a distance. If

*Shï-hsia-schan in Richthofen's spelling.

the older formations should become prominent, the forms would, in all probability, have the character of a disturbed mountain range, but after an interruption the lines of height become flat again and show the plateau structure which we had previously observed.*

In explanation of the apparently abrupt occurrence of the jagged mountain range, in the otherwise flat-topped plateau, von Richthofen infers an extension of the normal fault which he had observed 100 miles, 160 kilometers, further southwest, on the western side of the Fön-ho at the foot of the O-shan.†

Obrutschov‡ observed the same mountain range and gives the annexed diagram of its structure. He does not appear to find any ground for the existence of the normal fault inferred by von Richthofen, but accounts for the flattening of the mountain profiles toward the west by the horizontal attitude of the limestones on the summit of the arch. A translation of his explanation follows.

The road (leaving Yung-an-chön) leads toward west-southwest. At the north the cross profile of the Tsan-hua-shan ridge is very well shown, and the strata appear to and indeed do constitute a flexure. On the eastern slope they dip toward the east or east-northeast at an angle of 50° or 60°; near the crest of the ridge they bend over, and in their uppermost bed they lie generally horizontally, forming nearly flat folds; the more western beds dip very steeply westward, forming also flat folds of second grade (Fig. 53). The conditions of stratification can be especially well examined from the thickness of the dark, thick strata, probably Carboniferous limestone, which form vertical gorges on the upper part of the steep southern (probably downthrown) flank of the ridge; below these strata the mass of the ridge is probably made up in part of Sinian limestone, and below them of crystalline rocks which may be stratified.

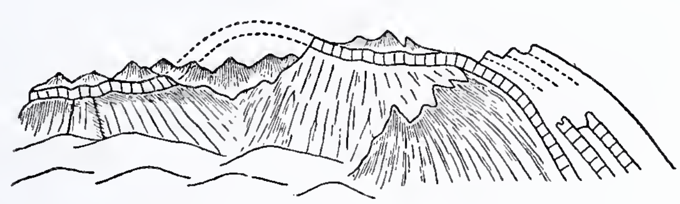


FIG. 53 (Obrutschov).—Wön-shui-hién, Shan-si. Diagrammatic section of Shi-hia-shan after Obrutschov.

We did not observe the occurrence of rocks below the Sinian system, but we inferred from the general dip of the limestones that such rocks must form the mass of the mountains west of the range. This inference

*China, vol. II, p. 432. "Denn an dem Weg nach dem grossen, in fruchtbarer Gegend gelegenen Wönn-shui-hsien sieht man den Plateau-abfall von einem zackigen, wenigstens zu 2500 Fuss über der Ebene aufsteigenden Gebirge, dem Shi-hsia-shan, überragt. Bald gewinnt man die volle Ansicht von Süden. In scharfem Contrast erblickt man neben dem horizontalen Schichtenaufbau der buntgefärbten Plateaugebilde ein mächtiges System dunkel erscheineder Kalke, die aber durch gelbe Schichtenabbrüche ihre wirkliche Farbe verrathen, in steiler Stellung aus dem Thal aufsteigen. Man ist geneigt, dies für ein weit älteres Schichtgebirge zu halten. Allein der weitere Verfolg rechtfertigt diese Vermuthung nicht. Der von Nordost nach Südwest gerichtete Gebirgsabfall ist zu Ende. In einer weiten Bucht erstreckt sich die Ebene nach Westen hin. Da die Strasse quer über die Bucht führt, so konnte ich nur aus der Ferne die Formen des Gebirgsabfalls in seinem westlichen Verlauf erblicken. Wenn die älteren Formationen hier herrschend würden, so müssten die Formen mit grösster Wahrscheinlichkeit den Charakter von gestörtem Gebirge tragen. Allein nach der einen Unterbrechung verflachen sich die Höhenlinien wieder und zeigen denselben Plateau-Bau an, wie wir ihn bisher sahen"

†China, vol. II, p. 421.

‡Central Asia and Northern China, 189–294, p. 171.

was confirmed by the observations of Prof. E. R. Lyman of the Shan-si University at T'ai-yüan-fu, who in a trip to the west of Fön-chóu-fu found granite and gneiss to be the prevailing rock for a distance of 20 miles, 32 kilometers. Lyman's investigation was for the purpose of ascertaining the source of supply of a fluorspar used for the manufacture of glass in the neighborhood, and he visited the locality at which it was obtained from granite. The observations of Obrutschov show that further west, approaching Yung-ning-chóu, the Sinian limestones again descend at dips of 10° to 20° to the northwest.

It appears clearly from the dips of the Sinian formation as well as from the distribution of the Pre-Cambrian and Paleozoic rocks that we have here a broad anticline, which, whether it coincides with a normal fault as von Richthofen supposed or not, is a feature of the earlier folded structure. This anticline lies in the strike of the great anticlinorium of Sinian rocks southwest of the Wu-t'ai-shan, which we followed southwestward as far as the Shï-ling, and the magnitude of the structures makes it probable that the fold is continuous, at least to the Shï-hia-shan west of Wön-shui-hién. The anticlinorium appears to pitch toward the southwest, as it is very much broader in the Wu-t'ai-shan region than near Wön-shui-hién, the arch in the latter neighborhood being in part at least capped by Sinian strata, but it is probable that the fold continues as a major feature of the structure toward the southwest, and would be crossed either as a belt of Pre-Cambrian rocks or as an anticline of Sinian between synclines of the coal-measure strata between Ho-chóu and Si-chóu.

South of Fön-chóu-fu, following down the valley of the Fön-ho, we had little opportunity to see the structure of the rocks, the Huang-t'u being everywhere the prevailing surface formation. Here and there, in the valley of the Fön-ho and in crossing passes between Ling-shï-hién and Ho-chóu, we saw outcrops of the Shan-si coal-bearing system, which exhibited moderate folding on a small scale. The cliffs of Sinian strata which cap the Ho-shan were seen in strike and therefore in apparently horizontal attitude, but the beds dip eastward and may be more or less folded beyond the range.

Bearing of Observations on General Structure.

That portion of western Shan-si which lies between the Fön-ho and the Huang-ho is discussed by von Richthofen as a plateau of nearly horizontal coal-bearing strata. Our own observations indicate that the rocks are folded to such a degree that dips of 10° to 20° are common, and even vertical dips may occur. The difference has an important bearing upon the coal resources of the region. If the general structure be that of a plateau of nearly level strata, coal is probably of very general occurrence

throughout the region. If, on the other hand, the strata are more or less folded, it is probable in view of the moderate thickness of the Shan-si coal-measures that the underlying Sinian limestone, and possibly the Pre-Cambrian rocks, constitute the surface over extensive areas, and the coal-measures occur in more or less restricted synclines. In general it seems probable that the structure of the so-called plateaus of Shan-si is marked by extensive folds having a north-by-east south-by-west parallel arrangement.

NORMAL FAULTING.

(See map, Plate XXIII.)

The normal faults of Shan-si and Shen-si lie *en échelon* in a curve of 450 miles, 725 kilometers, trending from south by west at the north to nearly east-west at the southwestern end, and convex toward the southeast. The downthrow is on the inner concave side of the curve, the upthrow on the eastern or southern side. The fractures are not continuous, as each one passes into a warped surface at either end. The altitude of the mountain ranges associated with the faults varies accordingly, and thus we have great crests like that of the Ho-shan alternating with moderate altitudes, which are crossed by the principal highways.

The most northern of the normal faults of this system is that along the base of the Ki-chóu-shan, bounding the Hin-chóu basin on its southeastern margin. Stratigraphic evidence of faulting is found near the northeastern end, where the Sinian strata are duplicated in the hills south of Tung-yü; but similar relations are not visible along the greater part of the course of the fault, as the rocks of the downthrow are deeply buried beneath the loess that fills the Hin-chóu basin. The straight front of the range, the manner in which the short ridges which mark it are truncated by steep triangular facets that fall approximately into a common surface, and the occurrence of slickens and grooves on such surfaces, suffice, however, to establish the fact of faulting. The preservation of slickens or grooves on the fault facets is, it is true, not common, as they are liable to erosion; but we have an observation by Blackwelder, who found them on a surface of coarse red granite, 4 miles, 6.5 kilometers, southeast of Han-yang, at a point where the rock rises with a steep front from the alluvial fans. He describes the surface as striking south 60° west, dipping 63° northwest, and strongly grooved in a vertical direction.

The second element of the fault system which we observed is the Ho-shan fault south of T'ai-yüan-fu. Between it and the Ki-chóu-shan fault there is a space of 75 miles, 120 kilometers, and the two are not in alinement. The more northern one ends further to the west. The Ho-shan fault runs about north 10° east, and defines the valley of the Fön from the vicinity of P'ing-yang-hién to abreast of Hung-tung-hién. Its length

is approximately 50 miles, 80 kilometers, and its greatest throw is east of Ho-chóu. Going from Fön-chóu-fu, we approached the Ho-shan in the vicinity of Kié-hiu-hién, and observed that toward the northeast the mountains sink away to relatively low altitudes and gentle slopes, whereas toward the south the range grows in height and becomes very abrupt in scarp. Its summit was capped with snow, and its relative altitude above the valley of the Fön-ho appeared to reach 5,000 feet, 1,500 meters. As the float in the streams from the range consisted chiefly of metamorphic rocks and the high crest exhibits horizontally stratified beds, we inferred that the mass was composed of Pre-Cambrian overlain by the Sinian. The valley in which we were traveling was cut in the Shan-si Carboniferous series, which was stratigraphically 5,000 feet, 1,500 meters, above the Pre-Cambrian, but is topographically 5,000 feet, 1,500 meters, below that geological plane. From our route to the base of the range was a distance of perhaps 10 or 12 miles, 15 or 20 kilometers, a hilly country covered with loess such as results from erosion of the soft strata of the Shan-si system. There was no evidence of the outcropping of the hard limestones of the Sinian, as must have been the case if the relations of the strata in the valley and on the mountain crest were established by abrupt folding. The stratigraphic relations, indeed, are such as to indicate beyond reasonable doubt the presence of a normal fault of 8,000 or 10,000 feet, 2,500 or 3,000 meters, throw. Physiographic evidence fully corroborates this inference, the mountain face having the character of a slightly eroded fault-scarp.

Opposite the Ho-shan and 30 miles, 48 kilometers, west of it is the O-shan (Ngo-shan) fault. It was seen by von Richthofen at San-t'iau-ho. He noted the occurrence of coal, which was mined in the valley of the Fön at the foot of the O-shan, then traversed a canyon in the limestone below the coal-measures, and ascending continually, both in altitude and geological position, he reached the village of San-t'iau-ho, where he again came upon the coal-bearing rocks.* The attitude of the strata in the canyon was nearly horizontal, but the altitude of the coal-measures in the mountain is such as to indicate a normal fault of approximately 2,000 feet, 600 meters, with the downthrow on the east†. Thus we have between the O-shan and the Ho-shan a sunken graben corresponding to the valley of the Fön-ho, bounded on the west by the uplifted block of the O-shan and on the east by the even more elevated block of the Ho-shan. It does not appear that the Ho-shan fault is continuous, either northward or southward, and we do not know how far the O-shan fault extends. As that of the Ho-shan passes into a warped surface, it is highly probable that that of the O-shan likewise does so.

*China, vol. II, p. 421. †*Ibid.*, p. 457.

In journeying from Chau-chöng-hién to P'ing-yang-fu, one at first has the magnificent scarp of the Ho-shan in view on the east, but southeastward the face sinks to a gentler slope and the mountains recede eastward from the valley. The profile of the crest declines at an angle of perhaps 10° and finally merges into a flat upland surface. Nearly east of P'ing-yang-fu another range, much less conspicuous than the Ho-shan, rises perhaps 2,000 feet, 600 meters. It is inferred from the aspect of the topography that the fault which is marked by the scarp of the Ho-shan dies out and passes into a warped surface, where the mountains become less prominent and the slopes less steep.

Southward from P'ing-yang-fu the route continues to the valley of the Fön-ho for 35 miles, 56 kilometers, and then leaving it, crosses an abandoned river valley to the basin of the salt lake, Yen-t'sï, at the base of the Föng-huang-shan. The mountains to the east are remote and it is not possible to observe their structural relations. The plain of the salt lake basin is an ancient alluvial plain, probably modified by lake and wind deposits. It extends with a gentle slope directly to the base of the mountains, which rise abruptly from it. The face of the range is remarkably steep and straight. Its slopes rise at angles of 25° to 40° to a height of 2,000 feet, 600 meters, or more without marked change. The alluvial cones are very small and the front is sharply but not deeply gashed with canyons. The larger spurs are truncated by triangular facets, which are considered to represent a fault-scarp and which extend westward to a bend in the range southeast of P'u-chóu-fu. Beyond this the features of a fault-scarp die out and pass into a steeply warped surface representing a once level plain now arched up and only in part eroded. The trend of the range changes from nearly east-west to south by west, and the heights decline in a remarkably straight line toward the Tung-kuan, the fortress at the narrowest point in the valley of the Yellow river. The Föng-huang-shan is like the Ki-chóu-shan in geological and geographical relations. In each case a bold mountain range rises abruptly from the broad basin which stretches along its northwestern base, and in each case the evidence of faulting is found in the character of the straight mountain front, which presents a surface not due to erosion nor greatly modified by it. The stratigraphic evidence is wanting, since the rocks on the downthrown side are in each case deeply covered by recent deposits.

Pursuing the chain of normal faults toward the southwest, we cross the Huang-ho from the province of Shan-si into that of Shen-si. The river makes a sharp elbow, turning from a southward course to one east by north, and passes between the Föng-huang-shan and the eastward continuation of the Ta-hua-shan. The crests of the two mountain ranges are nearly parallel, and the course of the river between them is taken on the

downthrown slope of the Föng-huang-shan block, a few kilometers north of the fault which skirts the base of the Ta-hua-shan (Fig. 54).

From Tung-kuan, where one crosses the river, loess-covered terraces extend in a long slope from the river southward to the base of the Ta-hua-shan. Further west, between Hua-yin-hién and Hua-chóu, on the southern side of the Weï valley, the Ta-hua-shan presents an extraordinarily precipitous character (Fig. A, Plate XXI). The level plain of the valley extends directly to its base, and cliffs of granite rise probably 4,000 feet, 1,200 meters, to extremely rugged summits. The crest is deeply gashed. The forms produced by erosion are controlled by systems of vertical joints which extend in two directions, the one parallel to and the other transverse to

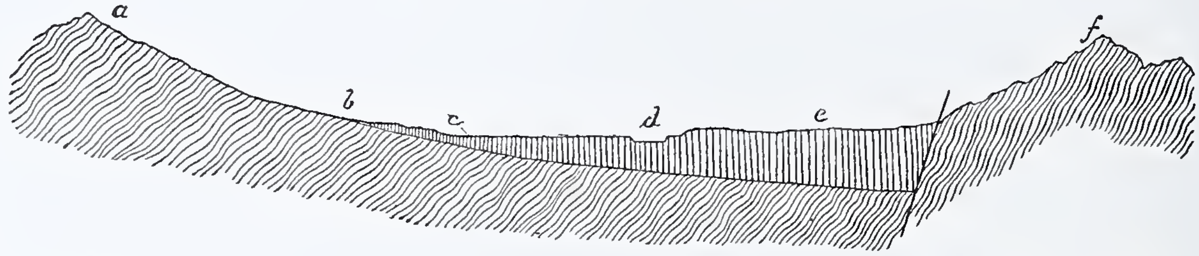


FIG. 54 (Willis).—Tung-kuan-t'ing, Shen-si. Cross-section of the valley of the Huang-ho, showing the general relations of the Föng-huang-shan on the north and the Ta-hua-shan on the south, and the position of the aggraded river valley along the southern, downthrown margin of the Föng-huang-shan fault-block. a = slope of the Föng-huang-shan; bc = irregular hills covered with loess; cd = terrace of the Huang-t'u formation about 38 meters above the river; d = channel of the Huang-ho; e = somewhat irregular surface of the Huang-t'u; f = upthrown block of the Ta-hua-shan. Horizontal and vertical scales indeterminate.

the course of the range, and they give rise to cliffs estimated in one instance to be at least 2,500 feet, 750 meters, at an angle of 70° or steeper. Further westward, the attitude of these joints changes from verticality to a nearly horizontal position, and the aspect of the mountain forms becomes milder accordingly (see Fig. B, Plate XXI). But while the jointing thus controls erosion forms, the face of the range continues abrupt and straight as far as Hua-chóu, and clearly represents a recent fault-scarp. West of Hua-chóu the range declines, and finally turns southward. The continuous plane of the front, which is most conspicuous in the lower and steeper slopes, extends around the curve toward the south, and is more or less covered with loess up to 800 or 1,000 feet, 250 or 300 meters, above the plain. Three miles, 5 kilometers, southwest of Hua-chóu, there springs from this slope a ridge or terrace, which presents a scarp about 700 feet, 200 meters, high as seen from the valley plain, and extends westward. It has a very flat gently-sloping crest, and where cut through by a ravine, some 3 miles, 5 kilometers, further east, it is seen to consist of Huang-t'u to the base. Its altitude at that point is between 300 and 400 feet, 100 and

A

B

A. Hua-yin-hién, Shen-si. View of precipitous face of the Ta-hua-shan; altitude approximately 4,000 feet; an element in the normal fault system of Shan-si and Shen-si; the scarp, one of the most precipitous seen, is a wall of granitoid gneiss rising directly from the alluvial plain of the Weï valley.

B. Lin-tung, Shen-si. View of western end of the Ta-hua-shan, illustrating occurrence of Huang-t'u formation on the slopes, the steep straight profile of the fault scarp, and spurs of gentler inclination which surmount the front. At this place hot springs with a temperature of 40° Centigrade issue from the fault.

A

B

A. Chóu-chï-hién, Shen-si. View of the northern front of the Ts'in-ling-shan, looking east, showing straight line of intersection of mountain range with plain of the Weï valley along that section which is considered to represent a normal fault scarp.

B. Taken from nearly the same position as A, but looking west, showing the gentle and irregular front of the Ts'in-ling-shan in that section which is regarded as a warped surface. The normal fault which defines the front in A extends to the extreme lefthand portion of this view, but quickly dies out.

130 meters. The relations which are expressed in Fig. 55 are those which are inferred. The diminishing fault is supposed to split; one branch continues westward, wholly in Huang-t'u, and gradually dies out into the plain; the other extends southwestward and probably passes into a warped surface. The phenomena are closely similar to those observed where the Föng-huang-shan turns south, near P'u-chóu-fu.

From Hua-chóu westward the profile of the range, in a section at right angles to its trend, is convex upward, somewhat as is that represented in Fig. 56 by the line *abc*. The steep lower facet *bc* is one of many which are nearly continuous along the range and fall into one surface, which is taken to be that part of the fault-scarp most recently exposed. The upper

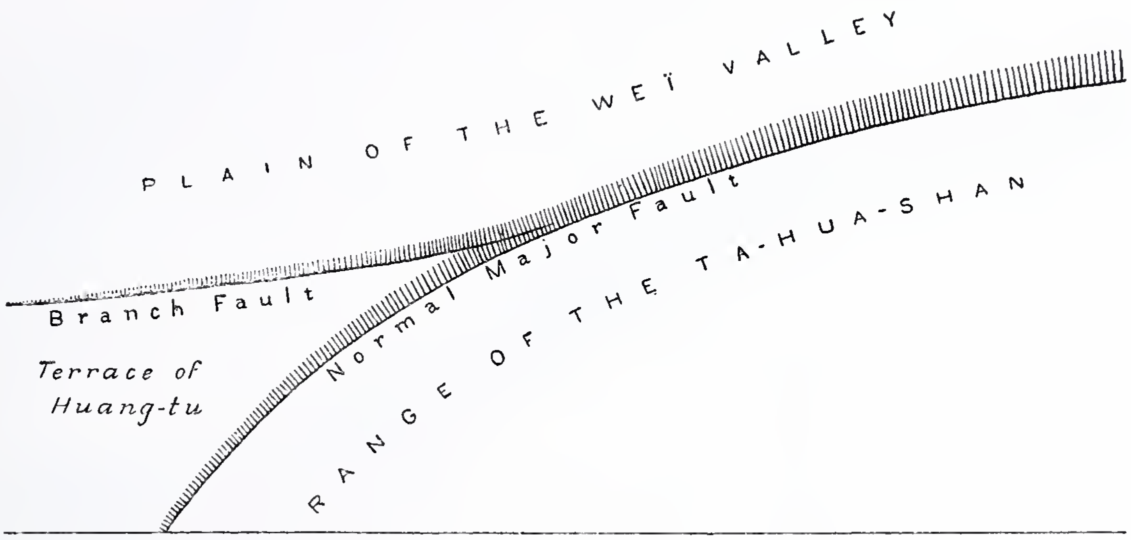


FIG. 55 (Willis).—Near Hua-chóu, Shen-si. Diagrammatic plan of the normal fault at the western end of the Ta-hua-shan, showing the branch fault which is believed to extend westward into the deposit of the Huang-t'u of the Weï valley, and to give rise to the terrace of that formation, which stretches westward from the main range.

portion *ab* is supposed to represent the older section of the fault-scarp, which has been more deeply eroded. The arc *abcd*, partly observed in the slope, but inferred between *c* and *d*, is believed to result from revolution of the mountain block about a fulcrum within it and between the northern raised margin and the depressed southern part.*

The occurrence of the Huang-t'u formation to a height of several hundred feet on the lower slopes of the Ta-hua-shan may result from either one or both of two conditions: faulting and eolian deposition. The Huang-t'u being deposited over the sloping surface of the fault-scarp, it is clear by inspection of Fig. 56 that part of the deposit would probably be raised with the mountain block, should movement now take place.

*In conversation with the writer Gilbert once gave this explanation of the profile of the Wasatch range, Utah, which the Ta-hua-shan closely resembles.

The Huang-t'u is believed to be older than the later faulting at least, and probably has been faulted. The fact that a fault-scarp extends out into the plain beyond the solid rock mass (Fig. 55) seems to be direct evidence to that effect, if it be substantiated. But those who doubt the recency of decided displacements may question whether the Huang-t'u could long maintain itself upon the slope.

Northwesterly winds sweep loess in great quantities up onto the lower slopes of the range; this can not be questioned, but it seems hardly probable that it can accumulate there under present conditions of alternating wet and dry seasons. In a subsequent chapter I discuss the climatic fluctuations suggested by the occurrence of the Huang-t'u and have

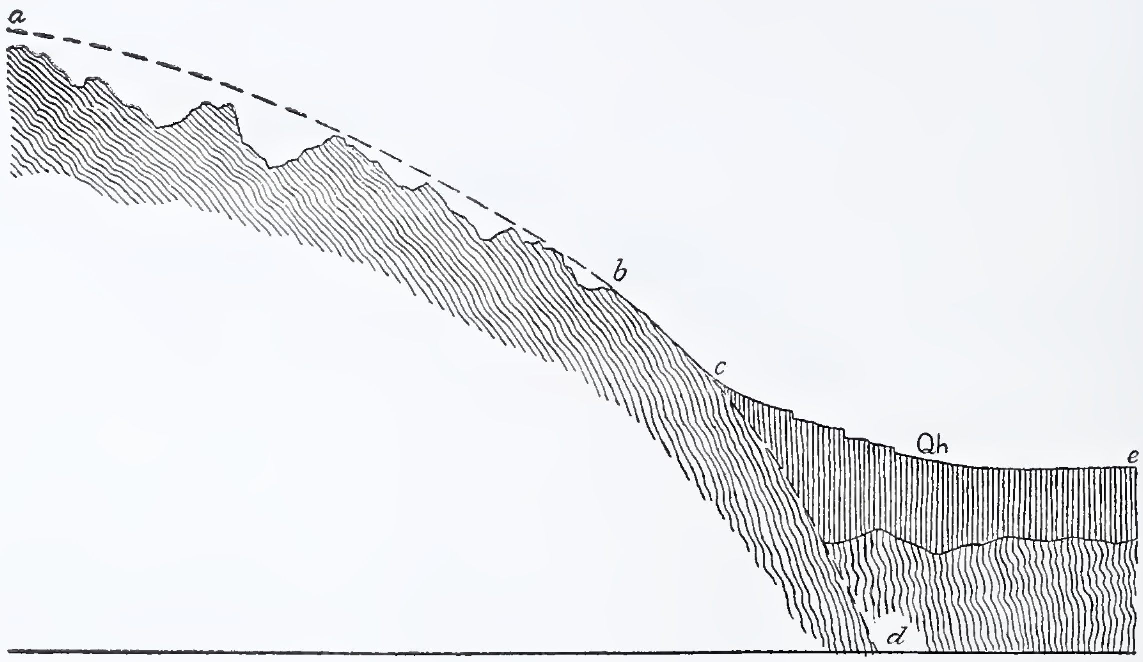


Fig. 56 (Willis).—Near Hua-chóu, Shen-si. Profile of the northern slope of the Ta-hua-shan, showing its peculiar convexity and the interpretation of the surface as that of a normal fault. The curve is believed to indicate a revolution of the mountain mass about some fulcrum within it. The rise of the Huang-t'u formation upon the lower slopes of the mountain is attributed either to faulting or eolian deposition.

attributed obvious wind-drifts of loess to a drier episode than the present. Thus I entertain the hypothesis that both faulting and eolian deposition have been instrumental in placing the Huang-t'u on the slopes of the Ta-hua-shan, high above the plain.

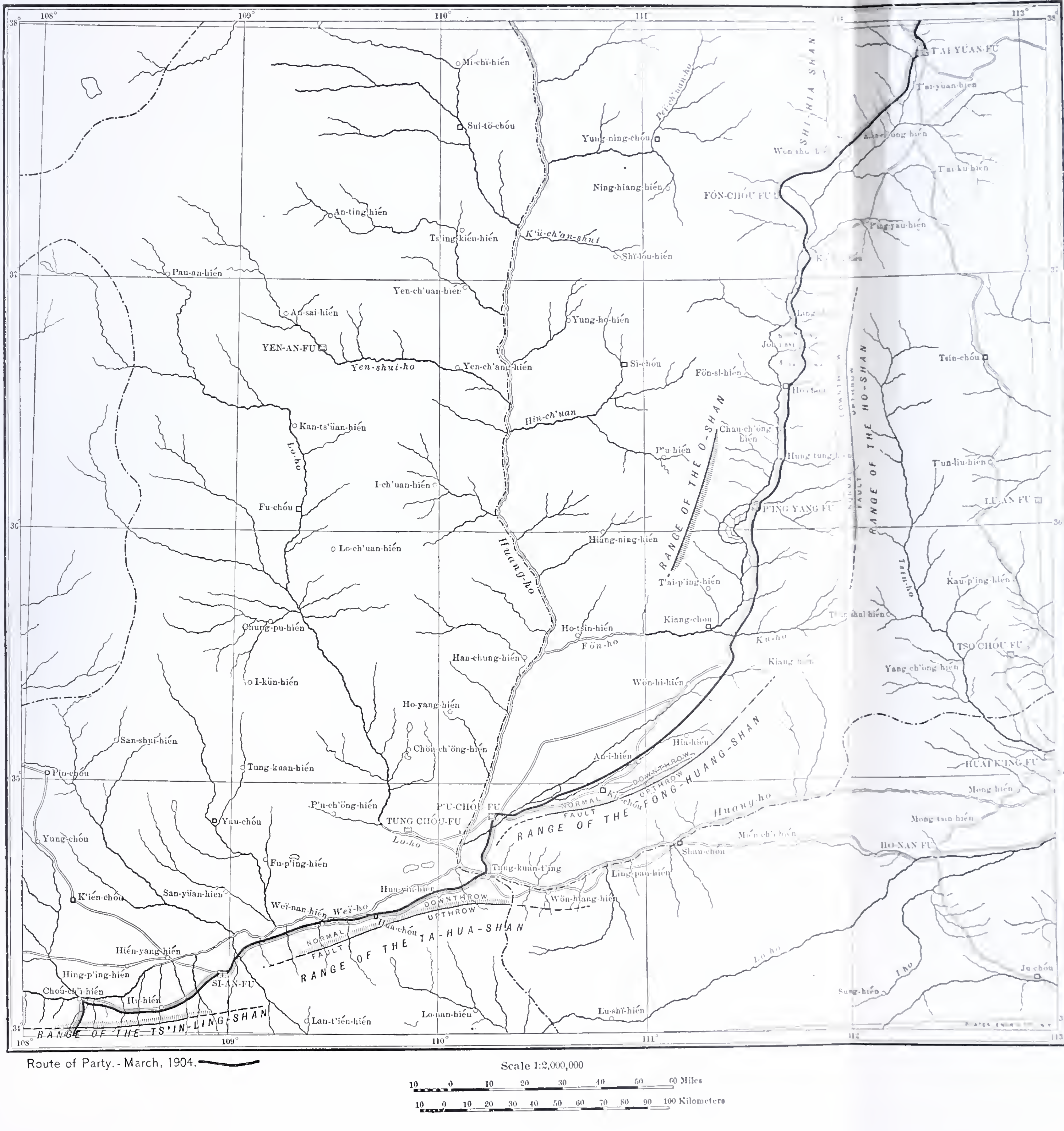
With the western termination of the Ta-hua-shan fault that range sinks away and the plain of the Weï widens some 15 miles, 25 kilometers, or more to the south, to the base of the Ts'in-ling-shan. This mountain range is again characterized by a remarkably straight front and by triangular facets cutting the spurs; it does not, however, exhibit the extremely abrupt rise from the plain which marks the Ta-hua-shan, at least not along

considerable stretches of its extent. As seen from Si-an-fu it appears to approach in height and boldness the Ta-hua-shan, but being 15 miles, 52 kilometers, or more distant its character evaded analysis. At Chóu-chï-hién, where we saw it closely, it presents the typical aspects of a normal fault-scarp, which involves not only the mountain block of Pre-Cambrian rocks, but also the loess of the valley plain. The features are expressed in the topographic and geologic maps (atlas sheet a 1) and in Plate XXII, giving views taken from near the base, at Heï-shui-k'óu, looking east and west along the front. This portion of the range is much less abrupt in its rise from the plain than it is further east, and toward the west it flattens out into a long gentle upwarp (see Plate XXII, Fig. B).

General Relations of the Normal Fault System.

The remarkable arc of normal faults thus followed throughout 450 miles, 725 kilometers, from northeast to southwest, extends around the southeastern boundary of the high plateaus of Mongolia, but lies well within the mountain ranges west of the great plains of China. It defines the great intermontane valleys of the Fön-ho in Shan-si and of the Weï-ho in Shen-si, and the courses of these streams, as well as that of the lower Huang-ho, are determined by the displacements. The Fön-ho lies in the graben of central Shan-si; the Weï-ho flows along the southern margin of the downthrown slope of northern Shen-si; and the Huang-ho, after flowing southward on that slope for several hundred miles, turns sharply at the base of the Ta-hua-shan, and passes out between the ranges on the lower edge of the tilted block. The normal fault system is thus seen to be a feature of notable magnitude in the structure of the continent.

One who regards the features of eastern Asia as a succession of steps, descending from the high plateaus southeastward to the plains, would expect the downthrow of these faults to be on the eastern or southern sides of the fault-scarps, which would face accordingly toward the east or south. With the exception of the relatively small fault of the O-shan, which marks the western side of the graben of central Shan-si, this is not the case. The downthrow is uniformly on the northwest, west, or north, and the great scarps face accordingly to the west or north. They overlook the country in that direction, and it thus appears that the descent from the high plateau to the plain is here interrupted by a feature of the first magnitude. Toward the east and south from the system of normal faulting, we have extensive mountain masses, which attain altitudes of 5,000 to 12,000 feet, 1,500 to 3,600 meters, and from which the descent to the plain is in part by faulting, with the downthrow on the eastern side, as described by von Richthofen for southern Shan-si, and in part by gently inclined warped surfaces.



NORTHWESTERN CHINA.

CHAPTER X.

QUATERNARY.

HUANG-T'U FORMATION OF NORTHWESTERN CHINA.

By Bailey Willis.

GENERAL DESCRIPTION.

The term Huang-t'u, the name of the village of Huang-t'u-chai,* is used in this report for that extensive deposit of yellow earth hitherto called the Chinese Loess. In giving a local geographic name to a locally developed formation, we are following a well-established practice, but are also governed by the more cogent reason that the term "Loess" should be limited in application to that peculiar material to which von Richthofen applied it. The translation of his definition follows:

The loess of China is, like that of the Rhine, an earth of brown yellow color, so soft that one can easily rub it to pieces with the fingers, and yet at the same time so firm that in places where through erosion, as by running water, large masses are broken off, it remains standing in perfectly vertical walls several hundred feet high. * * * It is so fine an earth that one can rub most of it into the pores of the skin; nothing then remains but some fine grains of sand, of which there are sometimes more, sometimes less. It is one of the most characteristic marks of the loess that these are angular, not rounded. By repeated washing with water, one can separate this from a much greater mass of material that may be called clay and is tinted brownish-yellow by iron. A third important element is carbonate of lime, which one may distinguish with the naked eye and which can be shown to be present by the use of acid.

*   *   *   *   *   *   *   *   *

On every bit of loess, even the smallest, one may recognize a certain texture, which consists in that the earth is traversed by long-drawn-out tubes, which are in part extraordinarily fine and in part somewhat coarser; which branch downward after the manner of fine rootlets and generally are coated with a thin white crust of carbonate of lime. If one examines the loess in place one sees that most of these little channels are nearly vertical, yet branch at an acute angle and downwards, whereby an incomplete parallel structure is maintained. If one is looking at a loose piece, but not exactly at the surface of parallel fracture, one sees the ends of the little tubes which occasion an appearance of minute

*Huang-t'u-chai, Yellow Earth Village, in the province of Shan-si, lat. 38°, long. 112° 40′, atlas sheet B II.

holes. But, apart from these definitely bounded elongated spaces, the earth between them has a loose porous structure and does not possess that close texture which is peculiar to other kinds of earth; for example, the clays, potter's clays, and loams.*

Adhering to von Richthofen's definition of "loess," we may define the Huang-t'u formation as that deposit of loess, sand, and gravel, which is wide-spread in the valleys of Chï-li, Shan-si, and Shen-si, which occurs to some extent on the adjacent mountains, and which forms the Great Plain of eastern China. It is characterized by the predominance of loess as a chief constituent, and by the vertical cleavage peculiar to that variety of clay deposit. It sometimes is and sometimes is not stratified. It contains notable quantities of the saline substances taken up by ground water; contains nodules of carbonate of lime, which frequently occur at definite levels and are set with the longer axis vertical; and includes land shells and occasional bones, as reported by von Richthofen.

In age the Huang-t'u ranges from late Pliocene or early Pleistocene to the present, it having been continuously in process of deposition throughout the Quaternary, and possibly since a pre-Quaternary date. Its age is more fully discussed in connection with the account of those physiographic stages (Chapter XI), with which the formation is intimately related.

The genesis of the Huang-t'u is also a physiographic rather than a stratigraphic question, and the reader is referred to the account of the stage of initial aggradation, the Hin-chóu stage. Our understanding of it may here be summarized as follows: In central and eastern Asia, in conse-

*China, vol. 1, pp. 56–58. "Der Löss von China ist, wie der des Rheins, eine Erde von braungelber Farbe, so mürbe das man ihn mit Leichtigkeit zwischen den Fingern zerreiben kann, und doch zugleich so fest, dass er an Stellen, wo zerstörende Einflüsse, z. B. fliessendes Wasser, ein Abbrechen grosser Massen verursacht haben, in vollkommen senkrechten Wänden von mehreren hundert Fuss Höhe ansteht. * * * In dieser Form ist die Innere Structur seiner mächtigen ablagerungen haufig auf beträchtliche Entfernung den Flusslaufen entlang entblösst. Er ist so feinerdig, dass man ihn fast ganz in die Poren der Haut einreiben kann; es bleiben dann nur noch einige feine Sandkörnchen zurück deren Menge nicht immer gleich ist. Es ist eins der am meisten characteristischen Merkmale des Löss, dass dieselben eine eckige, ungerollte Gestalt haben. Durch vielfach wiederholtes Schlemmen mit Wasser kann man diesen Sand von einem an Masse bedeutend überwiegenden, gemeinhin als thonig zu bezeichnenden Bestandtheil trennen, welcher durch geringen Eisengehalt braungelb gefärbt ist. Als ein drittes wesentliches Element kommt dazu kohlensaurer Kalk, den man zum Theil schon mit blossem Auge unterscheiden und durch Behandlung mit Säuren nachweisen kann.

* * * * * * * * *

An jedem, auch dem kleinsten Stück Löss lasst sich eine bestimmte Textur wahrnehmen. Sie besteht darin, dass die Erde von zum Theil ausserordentlich feinen, zum Theil etwas gröberen, gestreckten Röhrchen durchzogen ist, welche sich nach Art der Faserwurzeln von Pflanzen verzweigen und meist mit einer dünnen weisslichen Rinde von kohlensaurem Kalk bekleidet sind. Betrachtet man den Löss auf seiner natürlichen Lagerstatte, so sieht man, das die meisten dieser Canälchen nahezu senkrecht stehen, die Verzweigungen aber unter spitzen Winkeln und nur nach unten stattfinden, wodurch eine unvollkommene Parallelstructur bewahrt wird. Hat man bei einem losgelösten Stück nicht gerade einen Langsbruch vor sich, so sieht man nur die Enden der Röhrchen, welche ein fein durchstochenes Aussehen veranlassen. Aber auch abgesehn von diesen bestimmt begrenzten, gestreckten Hohlräumen hat die Erde zwischen ihnen ein lockeres poröses Gefüge, und besitzt nicht jene dichte Textur wie sie anderen Erdarten, z. B. den Thonen, Letten, und manchen Lehmen eigen ist.

quence of a change from moist to arid climate, a deep layer of decayed rocks was denuded of vegetation and exposed to effects of winds and occasional rains.* The disintegrated material was transported and sorted, both by wind and water; wind being the more effective agent during the dry seasons and on wide plains; waters doing a larger work during rainy seasons and in river valleys. Sorted and transported repeatedly and alternately by winds and waters, the material came to consist in great part of fine dust, the loess, which both agents could carry in largest amount; but this was always mingled, as it is now, with some coarser sand and gravel introduced by flood waters. Beyond desert basins, the path along which the Huang-t'u was distributed was chiefly down the valleys of a previous physiographic epoch, as it is now down the valleys of the present far more mountainous surface. It was deposited on flood-plains and in lake basins. The lighter portions of it were blown out onto mountain slopes and gathered beneath wind eddies or in sheltered hollows. In course of distribution it became thoroughly decomposed and oxidized; and where it accumulated and was exposed to subaerial conditions it acquired vertical cleavage, a secondary characteristic due to gravity and movement of ground waters, and became charged with salts brought in by such waters. The processes of transportation and accumulation are in progress now and are believed to have been similar in past ages.

DESCRIPTION OF LOCAL OCCURRENCES.

The description of local occurrences of the Huang-t'u formation, which is in its general aspects monotonous, necessarily involves some repetition. Wherever seen, its general characteristics are its constitution, its vertical structure, and, in valleys or basins, its slightly concave surface. The particular features which distinguish one occurrence from another are the greater or less proportion of coarse wash in comparison with the predominating constituent, the loess; or its occurrence in peculiar situations, where its presence is not readily attributable to the ordinary agents of deposition; and the presence or absence of stratification.

In the following paragraphs the notable occurrences of Huang-t'u along our route are briefly described.

The Huang-t'u formation constituting the Great Plain of eastern China is characterized in von Richthofen's geological map as alluvial loess, and such it is to a great extent, inasmuch as it is the deposit from the waters of the Huang-ho, which has filled in the space between the mountains of Chï-li and Shan-si on the west and those of Shan-tung on the east, establishing the seacoast far to the east of the position which it would otherwise

*Pumpelly. Relations of Secular Rock Disintegration to Loess, Glacial Drift, and Rock Basins. American Journal Science and Arts, vol. 27, 1879.

occupy under existing conditions of the altitude of the land. This alluvial deposit differs from ordinary river mud in that it consists chiefly of fine wind-sorted loess. We should not, however, too hastily infer that it has been brought to its present position by wind. On the contrary, the position of the flood-plain with reference to the relatively high river channels, and the obvious genetic relation existing between the silt-burdened rivers and the far-spreading plain demonstrate clearly that the deposit owes its distribution chiefly to muddy waters, which have built a very broad and very flat alluvial cone. The constitution of the Huang-t'u in this district is due to conditions in a remote region, from which it has been brought by the usual agents of transportation, the rivers. Nevertheless, the activity of winds is effective under existing climatic conditions, in consequence of which the plain is exposed without any covering of vegetation or snow during nearly half of each year. The fine loess, which was elsewhere sorted from the coarser constituents with which it originated, and which is here mingled with obdurate quartzose river sand, is separated from the latter by the action of the wind and sweeps in dust clouds over the plain. The sand, thus cleaned, remains to constitute sandy stretches and form dunes. The details of the distribution of these products of wind action are described for the Bay of Peking, in the chapter on artesian water supplies. The stretches of sand are usually adjacent to river courses, from which it is blown out by the prevailing winds, while the migrating dust clouds settle anywhere without reference to features of the surface, except in so far as the latter afford a lee or induce an eddy in the winds. About the hills there are usually places which offer shelter to the wind-blown dust and in which it accumulates in drifts. Where a range of hills extends for some distance across the current of a prevailing wind, the crest induces an eddy on the windward slope and the lower part of the hills becomes covered with loess up to a gently concave surface, which is that on which the scouring effect of the wind balances the tendency to deposition. This form of deposit is common throughout the mountainous regions occupied by the Huang-t'u, and the drifts of loess on the windward slopes are sometimes of notable thickness. Similar drifts may be found in valleys on the lee side of a range, but, contrary to what one might expect, they do not seem to be as deep or as extensive as those in concavities to windward.

We observed the alluvial Huang-t'u formation of the plain and its wind-derived products in Shan-tung about the margins of the peninsula, and in Chï-li en route from Pau-ting-fu to Ning-shan. A special study was made in the Bay of Peking, and it was there that the dominant importance of the rivers as the chief agents of distribution of the formation was first recognized.

The depth of the Huang-t'u in the Great Plain is indeterminate. At a maximum it may reach a thousand feet, 300 meters, or more. Toward the marginal mountains it gradually lessens by rise of the underlying rock surface, as water shoals toward a shore, and becomes so thin that hills protrude, and eventually the valley floors rise above the level of the plain of Huang-t'u. This is well illustrated in the geologic maps of the vicinity of T'ang-hién (atlas sheets G I and F I and in Plate XXIV). Northeast and southwest of Si-ta-yang is a flat surface, eroded on gneiss and Ta-yang limestone, which we regard as an old valley floor. It is thinly covered with Huang-t'u, which may be the remnant of a once deeper deposit of the Hin-chóu stage* or a more recent accumulation of wind-blown dust. In the Ning-shan basin there is a similar ancient valley floor, which is covered by the Huang-t'u to a depth of 25 to 40 feet, 7.5 to 12 meters, and possibly to a greater depth in some places. This deposit forms a terrace about 120 feet, 36 meters, above the present channel of the Hang-ho, and appears to have accumulated in the old valley before the modern canyon was cut. It may reasonably be regarded as a deposit of the Hin-chóu stage. We did not observe distinctive characters which would enable us to separate it from the relatively recent alluvial Huang-t'u of the Great Plain, but closer inspection might possibly discover them.

Along the Sha-ho across the divide into Shan-si and the Wu-t'ai mountains, the Huang-t'u formation, though not entirely wanting, is far less generally present than one might anticipate from accounts of its widespread occurrence in this part of China. After leaving the Ning-shan basin we saw nothing which could be distinguished from ordinary coarse alluvium until we reached the pass in the bend of the Sha-ho, 8 miles, 13 kilometers, northwest of Fóu-p'ing. At this point there is an accumulation of yellow earth having the characteristic vertical cleavage, yet mingled with much sand and gravel, which appears to have been deposited in the channel of the river when it still flowed in a straight course toward Fóu-p'ing and just before it was diverted eastward to the canyon in which it now takes its circuitous course. The deposit is very limited in extent and thickness, and is clearly a special phase of the alluvium of the Sha-ho.

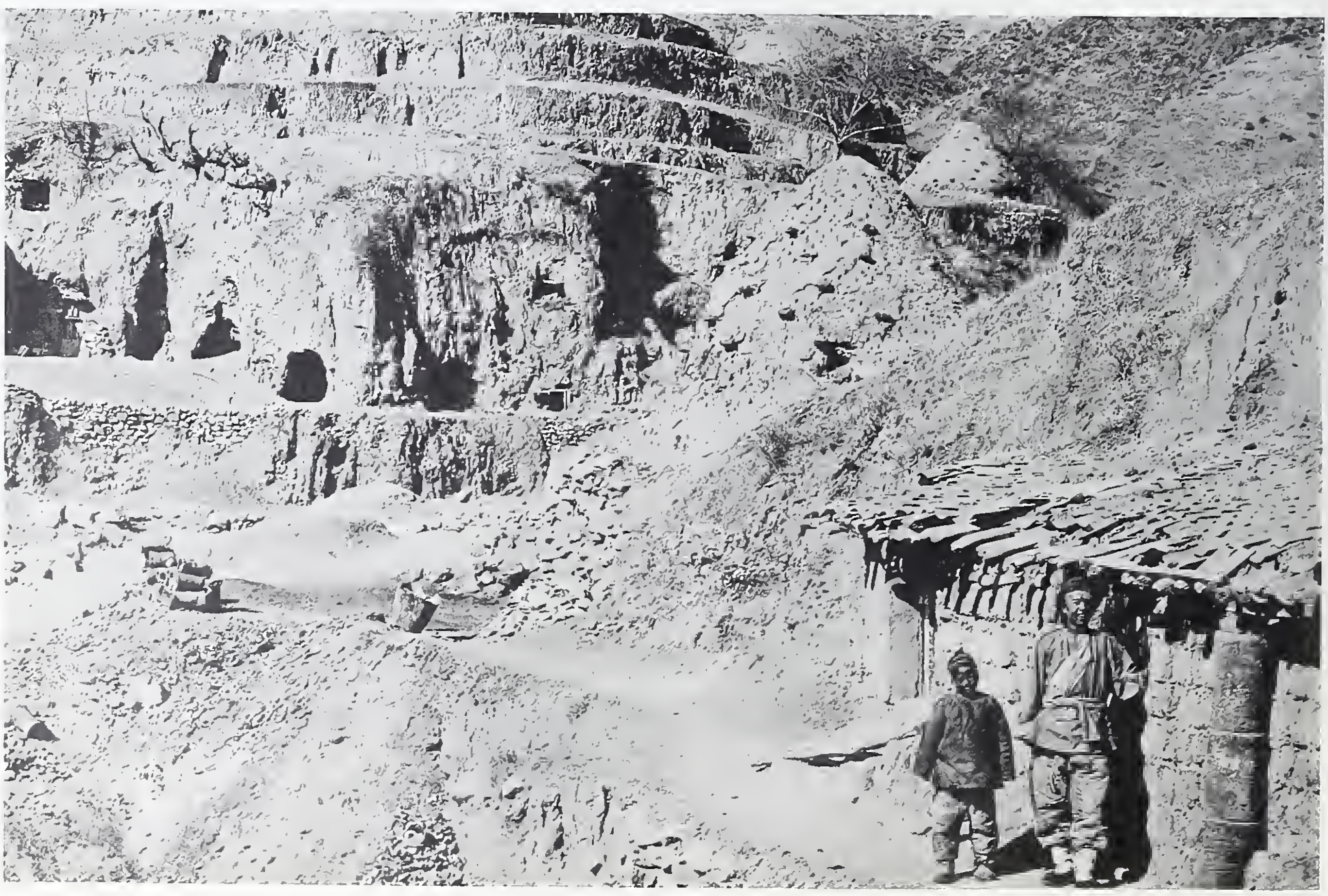
The divide between Chï-li and Shan-si, where flat, is thinly covered with residual soil, but not by the Huang-t'u formation. In this respect it resembles the broad summits of the Wu-t'ai-shan. The valleys of the Ts'ing-shui-ho and the T'ai-shan-ho are floored with beds of coarse gravel and obstructed by large alluvial cones of shingle, gravel, and clay, the wash of rock and residual soil on the mountain slopes, but there is no extensive

*The name Hin-chóu is given to a stage of physiographic history during which the Huang-t'u first began to accumulate; the last epoch of the Pliocene or the earliest of the Pleistocene.

deposit so characterized by loess as a chief constituent that it might be called Huang-t'u. Von Richthofen, in his hurried journey across the Wu-t'ai-shan during a December storm, was led to think that loess was found in every corner of these mountains, but he was misled by a few very limited occurrences. One of these is at the forks of the T'ai-shan-ho, just above Shang-ho-miau, where, in the eddy between wind currents blowing down the two valleys to their junction, there is a small deposit on the intervening spur. It is necessary to exaggerate the area in order to represent it on the geologic map. Another body of Huang-t'u is found just north of the village of Wu-t'ai-shan, in the acute angle between two gulches. It is of small extent and 25 to 30 feet, 7.5 to 10 meters, thick. The material is very fine and free from grit, and a careful search failed to reveal any pebbles or even large sand grains. It possesses the vertical cleavage, color, and other characteristics of the Huang-t'u of the Great Plain. We regard this deposit as a wind drift, owing its accumulation to special topographic conditions that induce local drafts and eddies. There are no doubt others like it which did not come to our notice. Again, a body of material having the characteristics of the Huang-t'u was observed in a hollow on the south-east slope of Nan-t'ai, at an elevation of about 6,500 feet, 2,000 meters. It may be a remnant of an early deposit antedating the present altitude of the region. As is stated in the discussion of the physiographic stages (Chapter XI) we are of the opinion that much of the area of the Wu-t'ai-shan was formerly covered with Huang-t'u at a time when the altitude of the district was very moderate, and it is not surprising that some remnants of the formation should remain, possibly *in situ* in an ancient valley as on Nan-t'ai, or as redistributed and redeposited bodies of the indestructible material in such situations as that near Shang-ho-miau and near the village of Wu-t'ai-shan.

Descending southward from the Wu-t'ai-shan, we entered the northern Loess Basins. Near the village of Liu-yüan (atlas sheet C I) we first encountered a notable development of the Huang-t'u formation, and thence throughout Shan-si it was a dominant feature of the surface. In the basin of Tóu-ts'un from Liu-yüan to Ts'ai-shï-ling, the formation is spread as a gently sloping floor, which reaches upwards on the hills by a gradual curve that becomes tangent to their bare slopes. It is scored by innumerable canyons from 20 to 100 feet, 6 to 30 meters, deep and is clearly revealed in section in their nearly vertical walls. In the center of the valley it is traversed by the beds of the tributary streams, which bring down great quantities of gravel. Sometimes the channel is deeply incised (Fig A, Plate XXV); elsewhere the flood waters spread widely over the plain, as illustrated in the panoramic view on atlas sheet D I. The distribution of Huang-t'u in this valley raises the question of the relative efficiency of wind and water in transporting and distributing it. It is clear that on the

A



B

A. T'ang-hièn, Chï-li, atlas sheet F I. View in foothills west of the city, showing an embayment partially filled with Huang-t'u formation. Hills present characteristic outlines of T'ang-hièn stage of physiographic development. The Huang-t'u shows the imperfect vertical structure which it frequently has where mingled with residual clay and gravel; it is considered to be a relatively modern alluvial deposit.

B. T'ién-hua coal field, Shan-sí, atlas sheet C I. View of bluff of Huang-t'u hollowed out for dwellings below, yet terraced and cultivated above. On the right are ovens used for burning pottery made from clays at the base of the coal measures. The Huang-t'u in this district is mingled with residual clay and presents a structure similar to that seen in A, but it lies in an abandoned valley of the T'ang-hièn epoch and is probably relatively very old.

A

B

A. Five miles east of Tóu-ts'un, Shan-si, atlas sheet C I. View of stream channel in Huang-t'u formation near eastern margin of the loess basin, showing how coarse material and loess become mingled in process of transportation.

B. Five miles northwest of T'ién-hua, Shan-si, atlas sheet C I. Bluff of Huang-t'u formation exposed in roadway 40 feet deep, showing interbedded wash from adjacent hills. This material fills the outlet of a small valley. The road occupies the channel of an intermittent stream. Men and boys carrying coal from the mines to neighboring villages.

slopes, whence every rivulet is now washing the loess, the formation could not now be laid down by streams. Neither does it exhibit in such situations stratification such as we might expect of water-laid material, and this fact weighs against the possibility that these particular deposits represent a former lake filling. They occur where wind drifts dust, as snow is drifted. On the other hand, the Huang-t'u formation, which constitutes the valley floor, is interbedded with frequent and irregular layers of gravel, with which it occurs in such intimate association that the entire deposit thus interbedded can be ascribed to one agent only, namely, torrential waters. Thus we are at once brought to recognize that portions of the Huang-t'u formation are laid down as alluvium, and that other portions, which lack the characteristics of alluvial deposits and occur in places where wind alone could drift them, are probably eolian.

Immediately east of Liu-yüan and 1,300 feet, 400 meters, above the valley in which the village is situated, is a parallel valley filled with Huang-t'u. The occurrence of the formation at this high level is peculiar, and unfortunately our observation of its characteristics was not so detailed that we can now discriminate between the hypotheses of its origin. It may be a remnant of a once more wide-spread formation at this level; or it may be a wind-blown drift caught in this high valley in consequence of the funnel-shaped hollow formed by the hills.

Following the highway southward from Tóu-ts'un, we cross a rock divide into the narrow valley of a small stream, which flows through a sharp defile into an adjacent basin. In this valley a bed of stratified clay and marl, with a few inches of peaty material overlying Huang-t'u, occurs under 10 feet, 3 meters, of the same formation. The sequence of strata implies a temporary water body intervening between two episodes in the history of the valley, during which the Huang-t'u accumulated. The condition probably was local and may have resembled that which now exists in the larger basin adjoining on the southwest.

By examining the topographic map C I, it will be seen that 4 miles, 6.5 kilometers, east by north of Wu-t'ai-hién is a pond to which three streams are tributary and which has no outlet. It lies in a depression which is a little more than 100 feet, 30 meters, deep, 2 miles, 3.5 kilometers, wide, and 5 miles, 8 kilometers, long. The depression is part of the valley of a stream which appears to have normal development, and one is surprised to note that the brook which runs by T'ién-hua does not drain the basin. It will be seen that the outlet of the valley toward T'ién-hua is narrow, a fact which may be attributed, in part at least, to the limestones which there form the hills, the wider valley being excavated in slates. It is also true that this outlet is in line with points at which the parallel, adjacent streams enter canyons, and along which an upwarp is recognized in the general features of the topography. The upwarp is not, however, the

immediate cause of the damming of the valley, as there is no rock sill at the outlet. The ravine at that point is filled with torrential wash and loess, constituting a typical deposit of stream-laid Huang-t'u (Fig. B, Plate XXV), and at the present time the little brook that flows northeastward to this point and then turns to the west to empty into the pond is building its alluvial cone across the valley. Thus the immediate condition is that of a valley dammed by the wash of a tributary stream. Within this basin the streams are now carried in elevated canals, and the waters are thus ponded at a level such that they can be used to irrigate the plain, which is in a high state of cultivation.

On both sides of the inclosed basin, which has just been described, northwest of Wu-t'ai-hién, are ridges which carry rounded hill-tops. The Huang-t'u formation lies upon the slopes of the hills, except where they are too steep, and extends over the saddles between them. It is not generally present on the summits, which are scoured by the driving winds. Yet there are hill-tops on which it occurs to a thickness of 10 to 20 feet, 3 to 6 meters, and of such extent that it is terraced and cultivated. These isolated patches resemble a capping of sandstone on a shale hill. The topographic form is that of a mesa, and the inference that we draw from it is that the loess cap is but a remnant of a once more extensive formation. Neither wind nor water could deposit the material in the situation in which it occurs, unless the adjacent valleys were likewise filled to a depth of 300 feet, 90 meters, above their present floors. We regard these mesa-like cappings as remnants, which indicate an ancient level of the upper surface of the Huang-t'u formation, and infer that since that condition prevailed there has been extensive erosion.

The valley of the Sing-ho below Wu-t'ai-hién presents very interesting occurrences of the Huang-t'u formation. On the northeastern side of the river is a terrace 125 to 150 feet, 35 to 45 meters, high, which is composed entirely of Huang-t'u. The material is nearly all fine loess and exhibits indistinct stratification, as though deposited in still water. It also shows the usual vertical cleavage. From this terrace the surface curves gradually upward to the near-by hills and becomes tangent to their slopes. On the left or northeastern bank the Huang-t'u continues for 5 miles, 8 kilometers, below Wu-t'ai-hién, and forms the northeastern side of the canyon for nearly 3 miles, 5 kilometers. The opposing slope throughout that distance is a steep surface of slate and limestone about 1,200 feet, 350 meters, high. While the wide valley about Wu-t'ai-hién belongs to a mature physiographic phase, the canyon is a feature of a younger and more recent phase—a feature due to warping. The deposit of Huang-t'u opposite the wall of slate and limestone can only have been made since

the canyon was cut out, and could not have been laid down by water so high on the mountain slopes. There seems good reason, therefore, to attribute this deposit on the left bank of the Sing-ho to the activity of the northwest wind, which sweeps the upper loess-filled valley and here rises over the converging heights, leaving its burden of dust in the concavity of their slope (see Fig. A, Plate XXVI).

Southwest of the Sing-ho there is a parallel valley in which an inverted stream flows northwest. The brook cuts a canyon 150 feet, 45 meters, deep in a deposit of Huang-t'u, which rises on the slope of the mountains to an altitude of 4,500 feet, 1,375 meters. The inversion of the stream is attributed to warping, but the accumulation of the loess, which here almost exclusively forms the Huang-t'u, is an effect of the northwest wind, which has brought it from the upper valley and deposited it in a situation precisely parallel with that on the left bank of the Sing-ho (see view on atlas sheet C II). A glance at the map southwest of Wu-t'ai-hién shows that the two wind drifts present similar features of slope and canyon, and that the plain south of Wu-t'ai-hién exhibits the form of a smooth hollow, which might be a plain of accumulation or a surface scoured by wind. In its detailed features it exhibits both aspects, for at times the rivulets carry back to it the dust which at other seasons the winds again sweep out.

Among the limestone ranges southwest of Wu-t'ai-hién is a wide plateau, the Yau-t'óu district, which corresponds with a syncline in the Ki-chóu (Cambro-Ordovician) limestones. An ancient valley from which the former river has been entirely diverted is represented at an altitude of 4,500 feet, 1,375 meters, by a surface eroded across the limestone and the sandy strata of the Shan-si coal-measures. Upon the old valley floor occurs a deposit of Huang-t'u, 20 to 30 feet, 6 to 9 meters, thick and of peculiar character. It is redder than that formation usually is, is more like residual clay than loess, and exhibits an imperfect vertical cleavage only. Regarding it as the alluvium of a valley dissected during the Fön-ho epoch, we consider this deposit to be of early date. Its present elevation is an effect of warping. A similar deposit of like age occurs in the T'ién-hua basin and is shown in the view, Fig. B, Plate XXIV.

In the valley of the Hu-t'o-ho near Tung-yü occur deposits of Huang-t'u closely resembling those already described, and we there observed the movement of the dust in a strong wind. It rose in a dun-colored cloud, which hid the hills at a distance beyond 2 miles, 3.5 kilometers. But the great body of material drifted near the ground, as snow drifts, and fell in sheltered spots where it rapidly gathered to a depth of many inches in a single storm. Had there been any grass or other vegetation, the surface thus covered would have been protected from the wind and would, to a

certain extent, have gathered the flying dust. But the river plain and hillsides, so far as they consisted of Huang-t'u, were absolutely bare, and every surface exposed to the attack of the wind was scoured, whereas every hollow became an eddy in which a drift accumulated.

The road leading southwest from Tung-yü traverses the flood-plain of the Hu-t'o-ho and enters a wind gap which is filled with Huang-t'u. At the narrowest point of the gap, 3 miles, 5 kilometers, from the village the road passes under a hill which rises 500 feet, 150 meters, above it on the northwest. This hill is capped by the Huang-t'u, a remnant of the once extensive formation which filled the valley to the level of 3,100 feet, 945 meters, or more above sea, that is, to a level but little, if any, below that of the plain about Wu-t'ai-hién.

In the hills immediately south of Tung-yü there is a very interesting occurrence of the Huang-t'u, at an altitude of 1,000 to 1,400 feet, 300 to 420 meters, above the Hu-t'o-ho. A spur of the Ki-chóu-shan, projecting northward east of Fang-lan-chön (atlas sheet C II) forms a triangular embayment which is drained toward the northeast. Within the rock rims of this embayment lies a body of loess. It exhibits the usual characteristics of vertical cleavage and lack of stratification, and appears, so far as a casual observation allowed us to judge, to be free from interbedded gravels. The position is higher than any body of Huang-t'u which we may reasonably attribute to alluvial deposition, except that which lies in the adjacent Yau-t'óu district, where the altitude is clearly the effect of recent warping. The position is one which is sheltered by ridges on the west and north from the winds that blow across the Hin-chóu basin or down the valley past Tung-yü, and thus appears favorable to the accumulation of wind-drifted loess. In the dust storm which we experienced near Tung-yü, drifts a foot or more deep accumulated in hollows having a like situation, and this body of apparently very homogeneous loess is probably in the same manner blown out of the adjacent valleys (see Fig. B, Plate XXVI).

In the Hin-chóu basin, which one enters in journeying southwestward from Tung-yü, the Huang-t'u formation covers an area of about 350 square miles, forming a wide plain across which flows the shallow Hu-t'o-ho, which is neither intrenched nor elevated. For the first time since leaving the Great Plain, we came into a region where the Huang-t'u is clearly related to the valley of a large river, where the interaction of the strong winds and constant stream might be studied. Our route lay nearer the mountains than the river, but we were able to note that here, as in the Bay of Peking, the water transports silt, sand, and gravel, which high water distributes according to the strength of current over the flood-plain, and which the

A

B

A. Four miles southeast of Wu-t'ai-hién, Shan-si, atlas sheet C I. View across canyon of the Sing-ho looking eastward: a general view of a deposit of Huang-t'u which consists chiefly of typical loess and is considered to represent an eolian drift blown from the immediate valley in to the hollow of the mountain slope.

B. Five miles east by north from Fang-lan-chón, atlas sheet C II. View from head of loess-filled hollow looking southeast toward the Ki-chóu-shan in Yau-t'óu district. The Huang-t'u deposit in this area is 1,400 feet above the valley and is thought to be an eolian drift.

Huang-t'u-chai, Shan-si, atlas sheet B III. View in lower part of loess basin of Huang-t'u-chai, showing characteristic erosion forms in stratified Huang-t'u. Note natural bridge over tunnel soaked out by water. In the distance the broad plain of the basin stretches eastward to limestone hills.

wind sorts and redistributes when the waters are low. This alternation of activities occurs during the rainy summer season and the dry winter season, in a manner which makes the winds especially effective, since at the time when they are active the ground is denuded of vegetation and unprotected by snow.

The level plain of the Hin-chóu basin affords no sections of the underlying Huang-t'u formation, and it is not possible to determine whether the material be stratified or not. We can only infer from the adjoining basin of Huang-t'u-chai on the south that the formation may be stratified as it is there. Along the base of the Ki-chóu-shan the Huang-t'u formation takes on a peculiar character, incident to the close proximity of the great fault-scarp. Along a portion of the base of the range alluvial cones rise to a height of 1,000 feet, 300 meters, above the plain and have a radius of from 2 to 3 miles, 3 to 5 kilometers, from the mouths of the ravines. With this great body of mountain wash is mingled the loess that is blown in quantities from the plain onto these lower slopes. We thus get a composite formation, in which sometimes the gravel and sometimes the loess predominates.

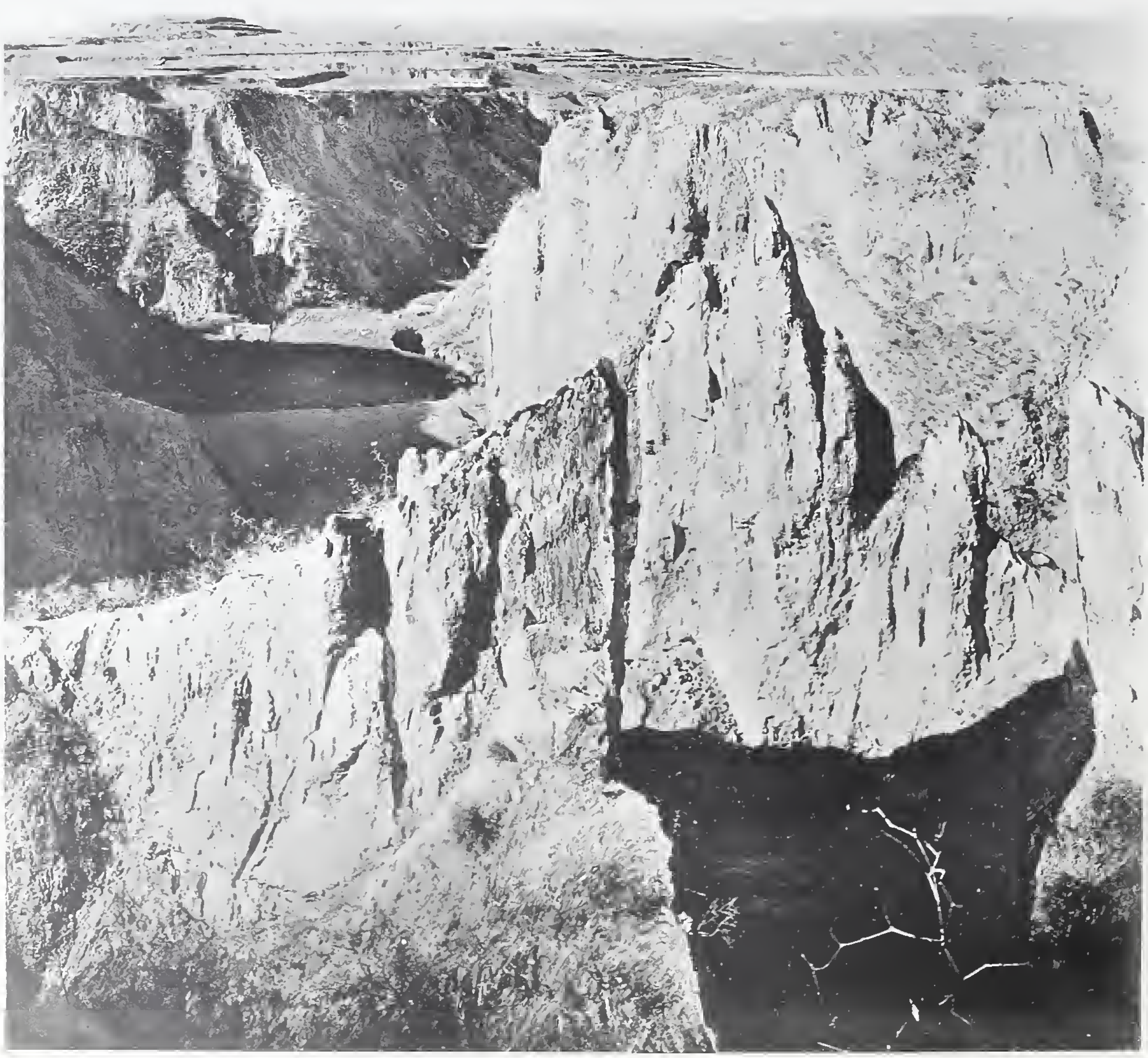
The Huang-t'u formation covers the Shï-ling pass, extending in a continuous sheet from the Hin-chóu basin to that of Huang-t'u-chai. The slope rising from the Hin-chóu basin to the Shï-ling resembles the curve by which the surface of the plain elsewhere passes into the declivities of the hills, and we recognize the form which is given by the drifting and scouring action of the wind. The slope is also scored by ravines, which display the vertical structure of the Huang-t'u, but if it was stratified we did not note the fact. On both sides of the pass itself the road lies in a cut from 20 to 60 feet, 6 to 18 meters, deep, which also exhibits a body of homogeneous loess. A single limestone outcrop protrudes through the general mantle near the center of the pass, and hills partly clothed with the Huang-t'u rise both east and west. There is no positive evidence of the fluviatile origin of the deposit in the pass, neither can we readily attribute it to the wind, since the situation is one which is subject to scour and unfavorable to accumulation. On the ground that the unfavorable conditions practically preclude eolian deposition, we incline to think that the body of material in the pass is continuous with that in the Hin-chóu basin and with that in the basin of Huang-t'u-chai, and is of alluvial origin. Its present altitude may be interpreted as an effect of the upwarp of the Ki-chóu-shan, to which the diversion of the Hu-t'o-ho from its former course through this pass is attributed. The surface forms of the slope, rising from the Hin-chóu basin and extending across the pass, are effects

of wind drift and scour, which would naturally be imposed upon a body of material so soft as the Huang-t'u.

In the basin of Huang-t'u-chai (atlas sheets B II and B III) the Huang-t'u formation is typically developed in various phases. South of the Shï-ling is a wide plain at an altitude of 3,300 to 3,500 feet; above 3,500 feet the hitherto gentle slope grows steeper and, between 3,600 and 4,000 feet, becomes tangent to the rock slopes of the hills. From north to south the plain is continuous from the Shï-ling (altitude 3,550 feet, 1,082 meters) to the margin of the bluffs above the channel of the northeastern branch of the Fön-ho, and it extends beyond to the southeastern hills. Toward the southwest it descends to the junction of the valley with the north branch of the Fön-ho, which opens upon the basin of T'ai-yüan-fu. This plain is a surface of the Huang-t'u, which, in its northern portion, exhibits typical relations with the environing hills.

The body of Huang-t'u beneath the plain is being dissected by autogenous canyons, some of which are 230 feet, 70 meters, deep and are the deepest we saw in the formation. They are locally cut down to bed-rock. The headward growth of these canyons is very vigorous, as is shown by changes which they have made necessary in the location of the highway, but only the main stream reaches across the basin. It is fed from a somewhat extensive watershed in the eastern hills, and may not have had an autogenous growth in the plain. Its northern laterals end abruptly in canyons in the Huang-t'u, exhibiting a transient phase which exists only while the ravine is developing across the plain; and it is evident from the moderate length of the canyons that conditions have not long been favorable to their development. In recent time one or both of two conditions have changed; either the plain has been raised relatively to the level of discharge of the main stream, or a desert climate has been replaced by a less arid one, or both changes have occurred.

The constitution of the Huang-tu in the plain is similar to that elsewhere throughout the northern Loess Basins. In the central part of the basin the material is largely loess and very fine sand, with some reddish clay and coarser sand. About the margins, drifted slopes consist wholly of loess, but, where streams debouch, the red soil and coarser wash they bring is widely spread and is interbedded at various levels in a manner to indicate that they were active from season to season, concurrently with the winds. At higher levels, as we observed on the summit which was occupied as a triangulation station west of the basin, there is a deep covering of reddish residual soil, which at the bottom contains bits of decayed limestone and is overlain by 10 to 20 feet, 3 to 6 meters, of loess. This soil



Pass of Si-yau-ling, 7 miles north of Ho-chóu, Shan-si. View of the Huang-t'u formation which, though now high above the valley of the Fön-ho, is stratified and resembles in nearly level surface and internal structure the same formation in lowlands about Huang-t'u-chai (see Plate XXVII). The formation is continuous from one locality to the other and is believed to have constituted a uniform deposit, which has since been modified by warping.

Twenty-five miles south of P'ing-yang-fu, Shan-si. View on ancient imperial highway showing the canyon developed in Huang-t'u by wear of traffic and wind. Two old levels of the road may be seen above the one in use, and the manner in which the long axles undercut the bluff may be noted; the endurance of the steep walls is indicated by depth of roadway.

appears to have been in part washed into hollows, since with the loess it is locally 80 feet, 24 meters, deep, but it has not been sorted by wind. It is clearly of local origin and survives from an earlier epoch, characterized by climatic conditions favorable to decay.

The Huang-t'u in the basin of Huang-t'u-chai is distinctly stratified, there being in the bluffs horizontal lines several feet apart, visible from a distance of 100 meters or so. They are not distinct lines of color, though they might appear as such if the surface were not covered with yellowish gray dust, but they come out as details of form in the sculpture of the cliff. This bedding was not observed in the loess of the higher slopes.

Both the stratified and unstratified Huang-t'u exhibit vertical cleavage. This structure occurs indifferently in the great mass filling the valley from top to bottom of sections more than 200 feet, 60 meters, deep and in the shallowest drifts on the mountain slopes, provided they are consolidated. It is poorly developed where the proportion of alluvial sand or gravel is large, and is wanting in eolian drifts from the latest dust storms. In the residual soil the structure resembles that of similar clays elsewhere, being of irregular fracture with a tendency to cave and produce steep or overhanging facets, that wear back to slopes.

In the basin of T'ai-yüan-fu we observed no peculiarities of the Huang-t'u especially worthy of note. The far-spreading plain, a surface of aggradation largely cultivated, afforded little opportunity to see sections, and we were unable to verify von Richthofen's inference that the basin is partly filled by lake deposits, though this is quite possible in view of the upwarp across the valley of the Fön-ho below Ling-shï-hién.

Between Ling-shï-hién and P'ing-yang-fu the Huang-t'u covers the uplands up to more than 1,500 feet, 450 meters, above the river. Underlying strata of the Shan-si coal-measures are exposed in many ravines, but the slopes are buried in fine silt to depths that range from 100 feet, 30 meters, to possibly 300 feet, 90 meters. The deposit is thickest next to the valleys, and is there interbedded with layers of coarse wash. Thus, north of Yön-yi-ssï, at an altitude of 700 feet, 210 meters, above the town, there is a 30-foot, 9-meter, bed of pebbles, up to 5 centimeters in diameter. The bulk of the material appears to be loess, but in the sections seen along the road the true constitution is obscured by a coat of dust, and coarser sand and gravels may be present in larger proportions than one expects. Vertical cleavage is everywhere characteristic, as shown in Plate XXIX.

About P'ing-yang-fu and thence southward the Huang-t'u is an alluvial deposit of the usual preponderant loess, with characteristic texture, and vertical structure, but horizontally bedded. Here and there occur layers of marl, in one case 30 feet, 9 meters, thick, overlain by Huang-t'u. Beds

of gravel and sand occur adjacent to tributaries of the Fön-ho. The upper surface of the deposit near P'ing-yang-fu lies about 80 feet, 24 meters, above the river, and throughout the valley rises gently to the mountains, east and west. Northward it is continuous with the surface descending from the upland of the Si-yau-ling, and southward it sinks to the level of the present alluvial plain of the Fön-ho, at its junction with the Kü-ho. In the shallow sections to the south of the Kü-ho, snail shells are especially abundant.

The continuity of surface, constitution, color, and structure, from the upland north of Ho-chóu to the lowlands south of P'ing-yang-fu, mark the Huang-t'u of the Fön-ho valley as a uniform deposit, which is throughout of alluvial origin, except where local conditions have determined the gathering of loess drifts from the alluvium. That the deposit is in part of earlier age and in part of current deposition is a fact which is of more than local significance. The Huang-t'u has been a continuous and continuously moving formation since its inception.

The conditions of accumulation of the Huang-t'u formation are intimately related to physiographic aspects of the region in which it now occurs, and of central Asia whence the material was derived. The reader is accordingly referred to the discussion of physiographic stages, where the origin and development of the Huang-t'u are considered under the head of the Hin-chóu stage (see Chapter XI).

ARTESIAN WATERS OF THE BAY OF PEKING.

THE SITUATION OF PEKING.

Before entering upon the investigation, of which the results are stated in the following pages, the writer deemed it improbable that a supply of good water could be obtained at Peking by a deep well. Accepting von Richthofen's theory that the Plain of Peking was composed of material chiefly carried and deposited by wind, he saw no opportunity for the occurrence of strata of coarse and fine material, such as are favorable to artesian conditions; but the facts observed are convincing evidence of the fluviatile formation of the plain and of its heterogeneous bedded character. Good water is found by wells 200 feet deep, and all the desirable conditions of an artesian fountain may probably be secured by a well 1,000 to 2,000 feet deep. In the absence of any supply of wholesome water, such a well is of vital importance to the American Legation, and, as demonstrating the resources within reach, would be a boon to the entire city.

The great plain of eastern China, in latitude 40° north, reaches into the mountains in the form of a bay, which is 45 miles across at its mouth on the southeastern side and extends 30 miles in a northerly direction. It lies across the trend of ridges whose opposed sections form parts of otherwise continuous ranges, and the level plain is related to the mountains about it as an arm of the sea is to lofty shores. This embayment is appropriately called the Bay of Peking, as the city of that name is situated at the mouth of it.

Two large rivers, the Peï and Hun, together with several smaller ones, enter this bay, flowing in general southerly courses. The Peï and the Hun have wide-branching head-waters in the mountains. They are subject to floods and carry large volumes of sediment. The Hun is said to be the larger stream in the rainy season, though it is considered a tributary of the Peï. The relative altitudes of the two show that the Hun has deposited more sediment than the Peï.

Peking is situated between the Peï and the Hun, 14 miles west of the former and 10 miles east of the latter, the American Legation site being taken as a reference point in the city. It is about 12 miles southeast of the base of the Western Hills and from 25 to 40 miles distant from mountains on the north, northeast, and east. The open plain slopes very gently away to the south and southeast.

The altitude of the Belgian Railway station west of the Ch'ién-mön is 45 meters, or 147 feet, above sea, according to official records furnished by M. Jadot, director of the railway. The American Legation site, near by, is a trifle higher, its altitude being about 155 feet above sea. By the same authority the altitude of the railway bridge over the Hun river at Lu-k'ou-kiau is stated at 66 meters, or 215 feet. The height of the bridge above the river being about 15 feet at low water, the river is in round numbers 50 feet above Peking.

The available figures for the relative elevations of Peking and the Peï river are based on readings of two aneroid barometers, one being read at Peking, the other being carried to Tung-chóu and read there as well as at Peking. It appears that Peking is 60 feet, more or less, above the plain of the Peï at Tung-chóu.

The altitudes of mountains immediately surrounding the Bay of Peking, as determined by the Intelligence Branch of the British North China Command, range from 1,500 to 4,200 feet above sea. The mountains are very sharply sculptured, are exceeding steep, and descend without notable foothills to the plain. Their rocky slopes continue beneath the alluvium of the plain. Spurs extend out into the plain like promontories into a sea, and isolated hills rise like islands through the deposits in which their bases are buried.

THE PLAIN OF PEKING.

To the unaided eye the Plain of Peking appears to be a monotonous level, in which artificial elevations are conspicuous because natural ones are wanting. Instrumental observations show that there are considerable differences of level between widely separated points, but the slope by which they are connected is so slight as to be inappreciable. Streams in their natural channels are rarely sunk a yard below the surface of the plain, which frequently descends slightly in a direction away from their immediate banks.

Hills which rise above the plain are of three classes—those which are the tops of partly buried mountains, those which are dunes of drifting sand, and those which are artificial. Among the latter is to be classed the so-called Coal Hill, in the Imperial City, according to the testimony of the most reliable observers.

The level of the plain extends, with remarkable uniformity, almost and sometimes quite to the base of the mountains, but wherever a ravine or valley opens onto it the surface is raised by deposits of gravel and sand from the mountain stream. These deposits constitute an alluvial cone, as it is called, which merges into the general imperceptible slope of the plain. Where many small ravines lie near together, their alluvial cones become continuous and constitute a belt. The head of an alluvial cone may lie high upon the mountain side, and in some instances such a one has been chosen as the site of a monumental tomb. That of Ch'i-yu-fön, 20 miles northwest of Peking, is a striking instance; the Ming Tombs are in part similarly situated.

It will be noted that the Plain of Peking is the surface of that earthy, sandy, and gravelly material which fills the embayment in the mountains. The constitution and arrangement of this material is of fundamental importance in the question of underground waters which may be reached by a deep well, and it has been made the object of such observation as is possible without boring. At Peking the surface, so far as can be seen, is composed of fine silt and sand. It has been worked over in the gradual growth and decay of the city or cities during ages, until its original condition and arrangement are lost. It is stated on good authority that foundations of old houses are found 25 feet below the present level. Three miles west of the west gate of the Chinese city, on the road to Lu-k'ou-kiau, very coarse gravel, mingled with fine sand, begins and is continuous thence to the Hun. This gravel is plainly the material distributed by the Hun in its latest excursions over the plain, together with dune sand and dust blown from other areas.

The valley of the Hun was examined as far up as San-kia-tién. It consists of an inner canyon of unknown depth, which is nearly filled with sand and gravel, and of an outer valley of moderate width.

In the northwestern part of the Bay of Peking the base of the mountains was skirted for 8 miles, from Chai-k'ou to Yang-fang. Near the hills, connected alluvial cones constitute a continuous zone of coarse gravel, which gives place, a mile or more further out, to a belt of sand, on which are situated the towns named Ch'ién-sha-kién and Hou-sha-kién, *i. e.*, Front Sand Town and Back Sand Town.

From Yang-sung to Chang-p'ing-chóu, a course of 7 miles northeast across the several streams which form the Sha, or Sandy river, the western branch of the Peï, the plain is nearly level and is composed of sandy loam. This loam packs hard, cracks in drying, and is separated by the wind into two parts: fine dust which rises in clouds in the air and sand which is blown along the ground.

From Chang-p'ing-chóu east to T'ang-shan Hot Springs, 10 miles along the mountain base, coarse wash from the hills lies in a belt north of a zone of sand and sandy loam, in relations like those noted along the western side of the bay.

From T'ang-shan south to Peking, 18 miles down the central line of the bay, the prevailing material is sandy loam like that already described. South of each of the streams flowing east is, however, a belt of sand, sometimes forming dunes 10 feet or more in height. These zones are produced by the north winds, which sweep the sand from the wide, slightly hollowed channels, in which the water is but a thread during much of the year, though a flood for a brief season.

Summing up these notes, it is apparent that the Bay of Peking is surrounded by a zone of coarse gravel next the mountains, within which lies a belt of sand also washed from the mountains, and that the great central area consists of fine sandy loam of a rather compact nature. This loam, on being redistributed by wind, gives rise to local sandy tracts and to dust storms.

From the preceding description it will be seen that the Plain of Peking is the upper surface of a body of material which fills a depression among the mountains as water fills an embayment along the coast. It appears also that the surface as we now see it is composed of wash deposited by rivers, together with local formations produced by wind. To these facts we may add the conception, concerning which geologists in general would agree, that the land formerly stood higher with reference to sea-level and has gradually subsided.

During this subsidence the sea and the rivers have been in constant conflict, the sea ever seeking to spread over the sinking land, the rivers ever bringing down sediment to build out the land. The delta of the Mississippi or the Nile or the Huang-ho illustrates the work of the rivers.

The subsidence and the filling-in have progressed gradually. There has been abundant time for the work of subsidiary activities on the surface of the filling, and we may thus conceive of the material beneath the present plain as having been spread and redistributed by streams and winds, as we now see it spread and distributed. At any particular stage of the process, at any level, there was coarse gravel near the hills and resting on bed-rock; there was sand along its inner margin, and the central area of the plain was composed of irregular stretches of sand and fine silt or clay.

A drill-hole sunk through this deposit should pass through many layers of clay, sand, and gravel of various textures and mixtures. Some may be small in area and isolated; others may be very extensive and connected with strata at much higher levels. The lowest, next to bed-rock, is probably the most extensive, as it must underlie the whole plain; the most open because it consists of the coarsest materials; and the one reaching to the highest levels, since it extends up onto the present mountain slopes.

Water may be found in any of the sandy layers. An artesian flow is most likely to be secured from the deepest.

Data for estimating the depth of filling of the Bay of Peking are meager, but not altogether lacking. The depression is recognized as a sunken valley, sculptured by running water. There are many examples of similar character and of like magnitude in the neighboring province of Shan-tung, and some of these have not been so filled as to hide the floor of the valley. The valley of the upper Wön-ho, near Lai-wu, east of T'ai-an-fu, is many miles across, is nearly flat over considerable areas, and is diversified and bounded by mountains which rise abruptly from it. The bed-rock is widely exposed. Reasoning from this comparison, we may infer that the slopes of the mountains about the Bay of Peking descend to a depth, which is probably not excessive, beneath the plain, and are connected by a comparatively flat floor. The fact that so large an area as the Bay of Peking has been filled by streams, which though of considerable size are not great rivers, is an argument in favor of comparatively moderate depth. At Peking it may be 1,000 feet from the surface to bed-rock; it probably is not 2,000 feet.

THE WATERS OF PEKING.

A small stream, the Tung-mi, enters the city from the northwest, feeds the canals and lakes in the Imperial City, and flows away through the Chinese city to the Peï river. It has no value as a source of water. Wells are numerous in Peking. Some of the principal ones in use by the

natives are seen on the streets. The deep grooves made by the ropes in the stone curbing testify to their constant and long-established use. They are shallow, are supplied by percolation in the uppermost strata, including the surface waters of the streets and houses, and are liable to go dry.

On the site of the American legation two wells have been sunk in the course of operations for building. The first proved inadequate. The second, 100 yards from the first, was sunk 32 feet, at which level water poured in in such amount that the work had to be stopped. The bottom is reported by Mr. S. H. Nealy, the architect in charge, as being a quicksand which had a tendency to flow to the southeast. This well has not been lowered by any draft thus far made upon it.

Wells, which are artesian in the sense that they reach flows beneath the surface waters, have been sunk by the Japanese in Peking with marked success. Regarding these the following facts have been ascertained:

A well in the Presbyterian Mission Compound is fitted with a windmill and is reported to yield a satisfactory supply.

A well in the Belgian Legation grounds is said by the Belgian Minister to be 60 meters (195 feet) deep, and to give excellent, soft water.

Regarding a well in the Methodist Mission Compound, Dr. I. T. Headland furnished the following facts: It is 210 feet deep, about 2.5 inches in diameter, and is supplied with a reservoir set in the ground which is 15 feet deep and 3 feet in diameter. The well was sunk by churning with bamboo poles shod with iron, without the aid of machinery. Yellow clay was added with water to prevent the sand from caving, but there was some trouble from that source. The bore is lined with bamboo, the joints being secured together with tin. The reservoir is built of cedar staves, and the bamboo tube is packed around with cork to make a tight joint where it passes through the bottom of the reservoir. The bottom of the well is in black sand. The water is soft and the supply has been entirely adequate for the demand of eight American families and about five hundred Chinese. It has hitherto been drawn by hand, but a pump and elevated tank are being installed. The well cost $1,200 in silver, or something less than $600 gold. It was finished in the spring of 1902 and its life is estimated at twenty years at least.

From the evidence of these three wells, which are somewhat widely spaced, it may be inferred that there is beneath a considerable part of Peking, at a depth of about 200 feet, a stratum of sand which is water-bearing. As the water does not rise above the surface, it is not confined in an artesian basin, or it comes from a source not notably higher than Peking. As it is unlike the surface water in the city, it is probably separated from the latter by an impervious stratum of clayey loam, and, being soft, it probably enters the ground in one of the sandy zones north of Peking,

whence it flows, chiefly in similar material, southward, underground. Its source may be in the vicinity of the Sha-ho.

Inquiries regarding the annual rainfall at Peking have not met satisfactory answers. It appears to be irregular in amount, there being extremes of wet and of drought. Dr. N. S. Hopkins, of the Methodist Mission, stated that measurements at a station some distance northeast of Peking gave 56 inches one year and only about one-eighth of that amount the next. During wet years the ground becomes saturated. During the dry years it is to a greater or less extent emptied by evaporation and seepage. The deeper waters are, no doubt, more constant than those near the surface.

There is good reason to believe that there is within reach of the people of Peking an adequate supply of wholesome water which may be reached by boring to moderate depth.

CHAPTER XI.

PHYSIOGRAPHY OF NORTHWESTERN CHINA.

BY BAILEY WILLIS.

INTRODUCTION.

The physiography of the plains and mountains through which we passed can not well be discussed according to limited districts, as can the geological formations. We have to deal with the features of the surface, which are, it is true, local, but which are so intimately related to those of adjacent and even of remote districts, that they should be treated as a whole. In the following account I shall consider the aspect of the different regions through which we traveled, from Pau-ting-fu, Chï-li, to Si-an-fu, Shen-si, first describing them as we saw them along our route, and subsequently grouping them according to relative age in order to discuss their significance in terms of mountain growth.

DESCRIPTION OF FEATURES ALONG THE ROUTE.

The plain (*Pau-ting-fu to Si-ta-yang*).—Pau-ting-fu lies in the alluvial plain of northern China, at an altitude of 60 feet, 18 meters, above sea, about 25 miles, 40 kilometers, from the foothills of the mountains of northwestern Chï-li. Our route extended thence through Wan-hién, T'ang-hién, and Si-ta-yang.* The great plain presents a monotonous surface, with no natural features which approach in prominence those of artificial origin. At Wang-tou-hién there is an artificial hill, probably 12 meters high, upon which a temple is built, which is conspicuous from all points of view on the adjacent plain. The streams are but slightly incised and the surface frequently slopes away from their banks, which are confined by more or less massive dikes. The rise of the plain toward the foothills is exceedingly gradual. In a distance of 12 miles, 19 kilometers, from Pau-ting-fu to Peï-p'u this rise is but 40 feet, 12 meters, and along our route the 100-foot contour winds in a general way parallel to the outer line of the foothills, at a distance of 4 to 5 miles, 6.5 to 8 kilometers, from them, while the 200-foot contour closely defines their bases. We may say that the slope of the plain varies, from 3 feet to the mile, .6 meter to the kilometer, at some distance from the hills, to 10 feet per mile, 1.8 meters per kilometer, as they

*See atlas sheets G I and F I.

are approached, and close to them rises to as much as 25 to 30 feet in a mile, 4.5 to 5.5 meters in a kilometer. The plain consists of the Huang-t'u formation, of which loess is the predominant constituent. Elsewhere sorted out by wind, the loess has reached its present resting-place as the alluvium of the Huang-ho and other streams, which traverse the western loess-covered districts. It is associated with quantities of coarser sand, and the two are vigorously re-sorted by the wind in all favorable localities. The streams, in times of torrent, redistribute the material over wide flats, from which, in the autumn and winter season, the winds carry away the loess in great clouds, and over which they distribute the sand in dunes. We thus find more or less extensive stretches of sandy soil or pure sand adjacent to the rivers, and wide areas of loess in the interspaces. The loess is universally cultivated; and so far as possible the sandy soils are improved, where they lie within reach of the river floods, by the construction of walls, which check the muddy waters and cause a deposit of the rich loess soil within the inclosure. The aspect of the plain is so modified by long-continued cultivation and artificial constructions that its natural features are subordinated. It is a vast alluvial flat, constantly swept by winds in the seasons when it is bare of vegetation and consequently covered by the sorted products of wind action, which are taken up in the season of torrential rains and redistributed by water, to be again sorted and redistributed by wind.

The margin of the foothills.—We skirted the edge of the foothills from Wan-hién to beyond T'ang-hién, and entered among them near Si-ta-yang, making excursions into them northwest of Wan-hién and from T'ang-hién as far as Nan-t'ang-meï and Mi-chöng. At the base of the more continuous heights is a fringe of detached hills, which rise from the plain as islands rise from the sea. They are, indeed, rocky summits, completely surrounded by the deposits of the plain. They attain altitudes of 100 feet to 1,200 feet, 30 to 350 meters, and many of them are extremely rugged in aspect. The summits vary from little points of rock just sufficient to afford an elevated position for a pagoda, such as that south of Chuang-li, to masses of considerable extent, such as that which forms the range north of T'ang-hién. Approaching them, one ascends over the gradually increasing slope of the loess, which is blown up onto them from the plains and passes frequently by a tangent curve to a slope of hard rock. Elsewhere, at points where the action of wind or water scours away the Huang-t'u, the rocks rise steeply. In ground plan the hills are extremely irregular, as they are in profile. They are composed indifferently of gneiss or limestone, and exhibit no special arrangement with reference to the structure of the subterrane, except such as is determined by the survival of heights of hard rock and the excavation of valleys on softer ones. They are thus features of mature

erosion, whose bases are buried under deposits foreign to their own development. Where gullies debouch from the hills upon the plains, one finds a gulch cut in the loess and sees the gravel from the hills and the loess interstratified in its sides. We have here the meeting place of detritus brought from above during the season of torrential rain, and dust blown from the plains during the season of drought and naked surface.

Along the foothills north of T'ang-hién and in the valleys northeast and southwest of Si-ta-yang, there is a plain which lies at an altitude of 600 feet, 180 meters, between T'ang-hién and Nan-t'ang-meï, and appears to slope southwestward so that between the T'ang-ho and Sha-ho it is but 400 feet, 120 meters, above sea. This plain is thinly covered with Huang-t'u, which only partly conceals the flat surface of gneiss and limestone underlying. At the present time the activities of streams are cutting deep headwater gulches, and in some instances they have reached through an outer range of hills and attacked the plain, as may be seen northwest of T'ang-hién. This feature is a valley plain of erosion developed by some river. The stream apparently flowed from the northeast, passing between T'ang-hién and Nan-t'ang-meï, across the course of the T'ang-ho at Si-ta-yang, and thence southward. The abandoned valley lies along the contact of soft gneiss with the harder Ta-yang limestone, and thus appears to have been adjusted to the rocks, whereas the course of the existing T'ang-ho is squarely across the strata, in a canyon which bears no relation to the structure.

*The Ning-shan district.**—The name Ning-shan of the principal town, 8 miles, 13 kilometers, northwest of Si-ta-yang, is applied to a district characterized by two mountain ranges, between which is a synclinal valley floored by Shan-si coal-measures. The mountains, extending from more continuous ranges toward the northeast, are cut by the T'ang-ho, by branches of the Hang-ho, and by the Sha-ho, into separate groups, the rivers flowing across the trend of the ranges. The peaks, which rise 1,500 to 2,000 feet, 450 to 600 meters, above sea, are bold and sharp in form, and near the rivers have steep canyon-like slopes. The town of Ning-shan lies in a relatively broad valley, which trends from northeast to southwest toward the Sha-ho. A transverse section of the valley from northwest to southeast shows that it is developed on the syncline, but exhibits, adjacent to the river and for a space of a mile or more on either side of it, a terrace at an altitude of 500 to 600 feet, 150 to 180 meters, above sea, or 100 feet, 30 meters, above the stream. This terrace is planed on the upturned edges of the coal-measures, and is thinly covered with Huang-t'u. In character and position it exactly parallels the similar plain observed between T'ang-hién and Nan-t'ang-meï, and presumably represents the

* Atlas sheet F I.

valley of a stream, which formerly flowed to the Sha-ho and possibly across the position of that stream southwestward.

The mountains of the Ning-shan district form a striking example of the complete adjustment of the topographic features of this region to the hard and soft rocks. The district is bounded along its northwestern side by normal faults, with downthrow to the southeast. If this faulting were still effective in determining existing relative altitudes, the Ning-shan area would be depressed and the region northwest of it relatively elevated. The reverse is the case. The limestone peaks, which are on the downthrown block, overtop the district of gneiss on the northwestern, upthrown block by 500 feet or more, and the sunken syncline of Paleozoic limestones stands out as an elevated peninsula, between the alluvial plain on the southeast and an extensive area of low hills on the northwest. Nevertheless, the streams which rise among those low hills flow directly across the belt in which the summit altitudes are greater.

*Bad lands of the Sha-ho.**—The Ning-shan district ends just east of Wang-k'uai-chön, and thence, westward to Fóu-p'ing-hién, the Sha-ho flows through a deeply eroded hill country of gneiss. The map scarcely suggests the intricacy of the little ravines, which branch in every direction from the deeply sunken channel of the Sha-ho into the uplands. The photograph (Fig. A, Plate III), taken from the summit of the high hill east of Fóu-p'ing, looking north by east, more graphically expresses the character of the region than can any description. The country is a "bad lands," having a relief of 300 to 1,000 feet, 240 to 300 meters, above the streams, with a general uniformity of hilltops and a monotonous similarity among thousands of short ravines. The rock in which the relief is sculptured is a gneiss of generally uniform texture and presents no differences of resistance to eroding activities. The general level of the summits probably corresponds to a plain of erosion, developed, it may be, by the Sha-ho at an earlier stage, or possibly by a stream older than the Sha-ho which flowed south by west along the belt of relatively soft gneiss. In the latter case the Sha-ho tapped and diverted the older stream, and the drainage assumed a course nearly at right angles to that which it previously had.

Mountains west of Fóu-p'ing-hién.†—The foothills west of the great plain may be said to extend as far as Fóu-p'ing-hién. Up to that point the general elevation is not much above 1,000 feet, 300 meters, and the isolated heights do not attain an altitude of more than 2,000 feet. A high peak is the hill east of Fóu-p'ing-hién, 1,900 feet, 580 meters, which is capped by siliceous limestone. It is an outpost of the western mountains, and just

* Atlas sheet E I.
† Atlas sheets E I and D I.

north and west of Fóu-p'ing-hién are heights of 3,500 feet, 1,000 meters, which are conspicuous buttresses of the main range. In 15 to 20 miles, 32 kilometers, we reach the divide, which is the boundary between the provinces of Chï-li and Shan-si, and on which the passes are 4,800 feet, 1,450 meters, or more; and the summits 6,000 to 7,000 feet, 1,800 to 2,100 meters above sea. The mountains of this eastern slope are angular in contour and ragged in profile. There are no smooth flowing curves, scarcely any soil-covered surfaces. Bare and sharply cut, they exhibit every bed and joint of the ancient igneous complex from which they are carved. (Fig. A, Plate XVII). They lie in a zone of climate unfavorable to protective vegetation, but this fact alone is not sufficient to account for their aspect, the more effective cause for which is their nearness to the very energetic river, the Sha-ho.

The valley of the Sha-ho above Fóu-p'ing-hién is peculiar. In direct line with its course past the city is a valley occupied by a brawling brook which has a rapid fall in its lower stretch, but less fall in the upper reach. At the head of the brook, 5 miles, 8 kilometers, above its mouth, the divide consists of the Huang-t'u formation, that is, of loess and stream gravels interbedded, filling an old channel. From the divide a rivulet runs northwest in inverted direction. To the mouth of this brook the Sha-ho comes from the northwest. It meanders in a canyon, one wall of which is a precipice 1,500 feet, 450 meters, high, and which is much narrower than the direct valley of the brook. About 8 miles above Fóu-p'ing-hién the Sha-ho forks, the main river coming still from the northwest, a smaller branch from the southwest. This southwest fork of the Sha-ho passes Li-yüan-p'u in direct course for Fóu-p'ing-hién, but turns into a canyon, in which it meanders in small oxbows to the northwest branch.

It is evident that the direct valley from Li-yüan-p'u to Fóu-ping-hién was formerly the course of the southwest fork, which was diverted by the cutting of the relatively young canyon. The conditions under which this diversion was accomplished and the deep canyon of the Sha-ho sawed out are discussed on a subsequent page.

Above Li-yüan-p'u the valley of the southwest fork is aggraded with heavy mountain wash and is wider than one would anticipate in comparison with the canyons below. This peculiarity is no doubt related to the conditions of diversion. It is not attributable to the occurrence of softer rocks in this section as compared with those in the canyon section, since the mountain masses consist throughout of Fóu-p'ing gneisses. The plan of the valley above Li-yüan-p'u is that of a straight, growing branch, dividing into many smaller ones at the outer end. For 6 miles, 9.5 kilometers, it is direct in its course and confined between two bold mountain spurs which narrowly limit the tributary brooks. Beyond the 6 miles,

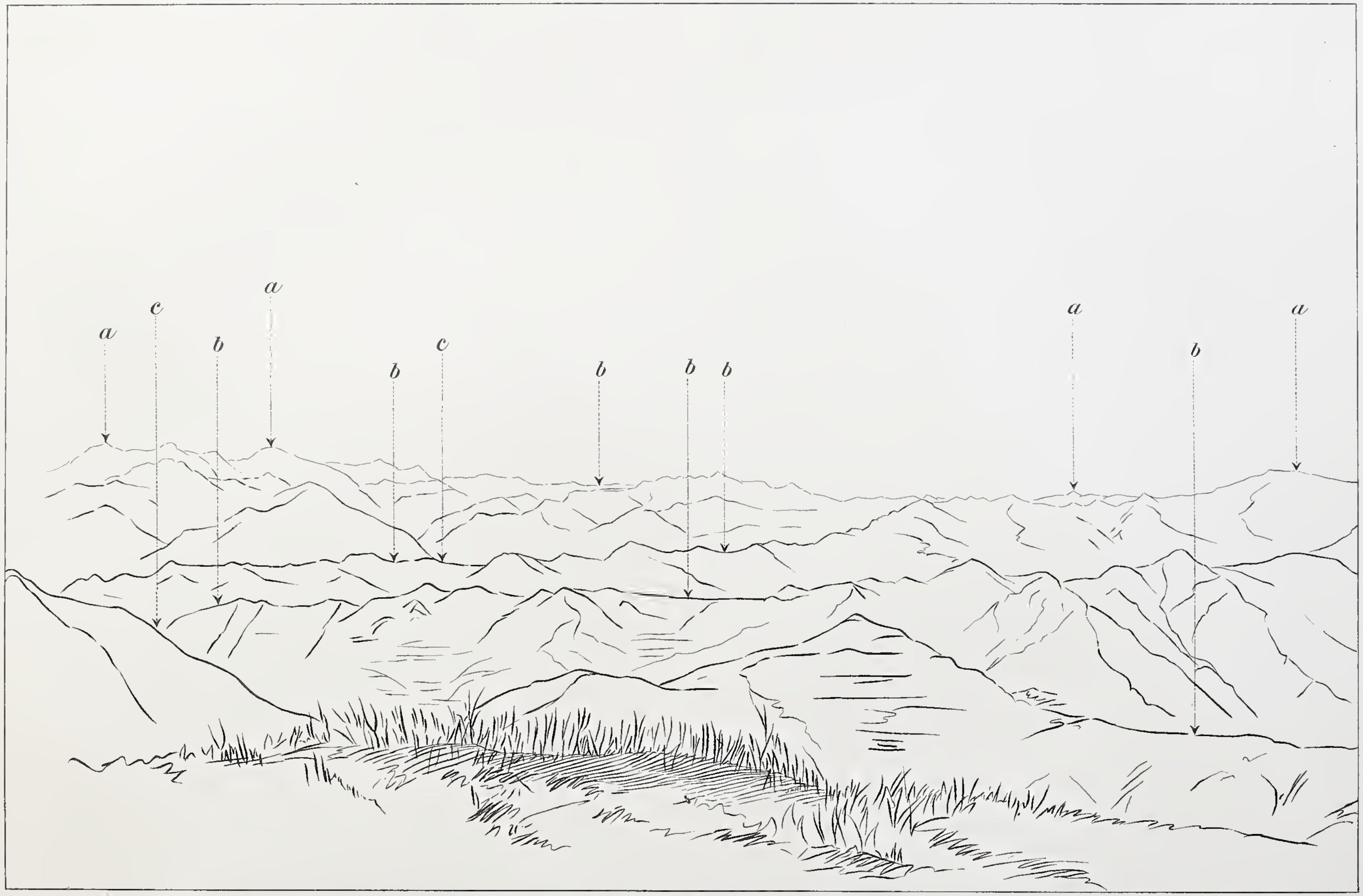
9.5 kilometers, it extends into five principal ravines, and each of these into several long gullies. The mountain slopes are very steep and the summits castellated, but the valley is not bounded by cliffs as is the case in the canyon stretch below Li-yüan-p'u. At an altitude of 4,400 feet, 1,330 meters, above sea—that is, about 1,800 feet, 550 meters, above the river—there is a well-defined terrace cut in the gneissic rocks, which, being generally cultivated, is evidently covered with soil. It is brought out by the contours on Sheet E I in the slopes above Lung-ts'üan-kuan.

*Chï-li-Shan-si divide.**—At the head of the Sha-ho is the divide between that stream, which flows directly southeastward, and rivers which have a southwesterly course. The divide is marked historically as the site of the south branch of the Great Wall, a work which was here carried out only in the neighborhood of the most important passes. Its construction shows, however, that the route which makes use of the valley of the Sha-ho was traveled at least two hundred and twenty years B. C. The general elevation of the divide is 5,800 to 7,000 feet, 1,750 to 2,100 meters, and the lowest pass above Lung-ts'üan-kuan is at an altitude of 4,800 feet, 1,450 meters, above sea. Several long spurs extend southeastward, with crests at 6,000 to 7,000 feet, 1,800 to 2,100 meters. They are quite strikingly serrate and some of the pinnacles along their crests are almost inaccessible. On the northwest the valley of the Ts'ing-shui-ho lies close to and parallel with the divide, at an altitude of 4,400 feet, 1,340 meters, that is, nearly 2,000 feet, 600 meters, above the valley of the Sha-ho on the eastern side.

The summit of the range is broad and rounded, covered with residual soil and grass grown. Several deer came bounding in even leaps over the rolling surface; in an instant they dropped out of sight in the head of a deeply cut ravine, as deer on the prairie disappear over the brink of a canyon. This upland is overtopped by peaks, which attain 7,000 feet, 2,100 meters, above sea, and are usually angular and precipitous rocky heights.

The Wu-t'ai-shan.—To the west of the Chï-li-Shan-si divide one looks across to the so-called plateaus of northern Shan-si. It is difficult to justify the application of the term plateau to the intricate system of mountain ridges and summits which meets the eye. At one's feet is the canyon of the Ts'ing-shui-ho, which sinks rapidly toward the southwest. Beyond are the long spurs of the ridge between the Ts'ing-shui-ho and the T'ai-shan-ho, and in the far distance the summit of the Wu-t'ai-shan, 8,000 to 10,000 feet, 2,400 to 3,000 meters, above sea, the highest range in the province. A leaden sky cast a uniform light over the bare, brown mountains the day we climbed the watch-tower north of the pass and the camera was useless. Hence the sketch, Plate XXX. A similar view is

* Atlas sheet D I.



View from watch tower on the Great Wall west of Lung-ts'üan-kuan, Chï-li; looking west over the mountains of Shan-si. aa = summits, which approach the Peï-t'ai stage; bb, ridges corresponding to valley levels of the T'ang-hién stage; c = canyon of the T'ai-shan-ho, of the Fön-ho stage.

View from the Chï-li-Shan-si divide, 5 miles south of Lung-ts'üan-kuan, atlas sheet DI; looking west by north up the old valley of the T'ai-shan-ho to Nan-t'ai.

given in Plate XXXI, taken 4 miles, 6.5 kilometers, south of the first, one view being south, the other north of west. The summits which are marked *a* rise above the long level spurs, marked *b*, and are connected with them by many accidents of slope and shoulder. Hidden behind the ridges are the canyons, to which the line *c* directs attention. The view is one of a surface which has a complex history of uplift and erosion, a history expressed in the relations of the several features; but it is necessary to penetrate further before attempting to unravel their sequence.

From the Chï-li-Shan-si divide we descended into the canyon of the Ts'ing-shui-ho, which, in this district of Pre-Cambrian schists, is bounded by slopes of relatively moderate inclination. The Ts'ing-shui-ho joins the T'ai-shan-ho, and the two flow southward in a channel which grows wider until, entering the mountains of Sinian limestone, it becomes a narrow, steeply walled gorge. The bottom of the canyon is filled with the coarsest shingle, and the streams meander in ever-changing channels from side to side. Our route turns up the T'ai-shan-ho and follows that stream to the village of Wu-t'ai-shan, the road being a mere track over coarse gravel (Plate IV). An alluvial cone of great size lies at the mouth of each tributary gulch, evidence of the rapid and vigorous denudation of the mountains. These cones appear to be young, the material having accumulated from the little streams, but not yet having been carried far by the larger T'ai-shan-ho, and the reason for their recent development is found in the fact that the forest has been removed from the mountains in the last two hundred years. Before that time the region had been occupied only by the priests living in monasteries, which, to the number of seventy, are built at Wu-t'ai-shan and elsewhere among the mountain recesses; but within two hundred years the Emperor Kang-hi promoted immigration into the mountains and allowed the people to cut the timber. The complete destruction of the forests has been accomplished in that brief time and the denudation of the mountains is proceeding at a very rapid rate.

The gorge of the Tai-shan-ho, like that of the Ts'ing-shui-ho, is cut in the Pre-Cambrian schists and in general presents sides of moderate slope, but here and there, where it crosses quartzites or conglomerates, the walls rise boldly several hundred feet. In its upper reach, near Wu-t'ai-shan, the valley, in chlorite schist, widens and branches extensively, and the slopes of the main Wu-t'ai range, including the summits of Tung-t'ai, Peï-t'ai, Chung-t'ai, and Si-t'ai, are broad and smooth. The general character is illustrated in the panoramic view from Nan-t'ai toward the northeast and north (see atlas sheet E I) and in Fig. B, Plate XXXII, which extends that view westerly. It would be difficult to exaggerate

the utterly bleak and barren character of these denuded mountain crests, 8,000 to 10,000 feet, 2,400 to 3,000 meters, above sea.

Northwest of the summit of Wu-t'ai-shan and 30 miles, 50 kilometers, distant is the valley of the Hu-t'o-ho, which at Tai-chóu has an altitude of about 2,000 feet, 850 meters. The O-shui-ho and other streams, which flow from the range toward the northwest, thus descend, approximately, 6,000 feet, 1,800 meters, in 30 miles, 50 kilometers, and lie in very deep, steep canyons. In similar rocks the gorges are much more precipitous than those of the Ts'ing-shui-ho and upper T'ai-shan-ho, as we might naturally expect them to be from the very much greater fall of the streams. Near Yen-t'ou the Sinian limestones overlie the Wu-t'ai schists, forming cliffs of very striking character; and it is this northwestern canyon which justifies von Richthofen's description of wild scenery and dangerous paths.

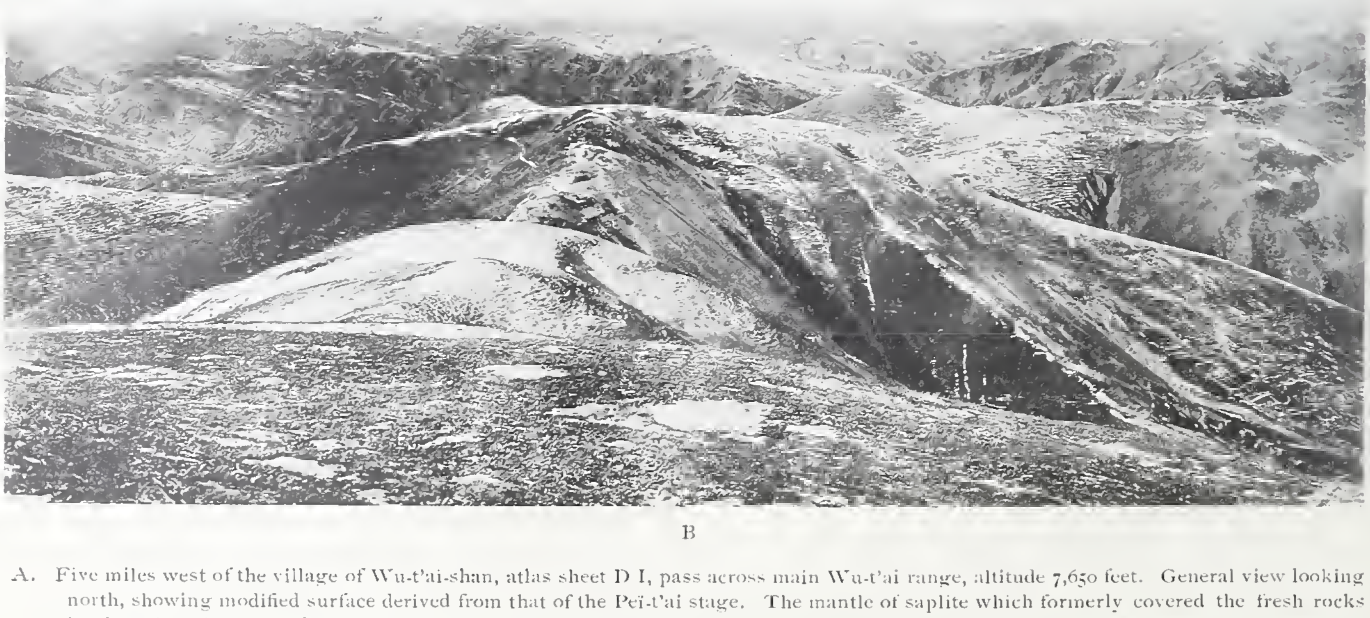
If we consider the relations of the O-shui-ho and the Sha-ho to the mountain mass between their head-waters, we see that the latter lies like a broad ridge between them, subject to their successful attack. Having relatively great fall and especially steep head-gorges, the O-shui-ho and Sha-ho are energetically pushing in the divides and so reducing the drainage area of the intermediate streams.

In the course of our wanderings in the Wu-t'ai-shan we crossed several of the passes at altitudes of 7,000 or 8,000 feet, 2,100 or 2,400 meters, and visited or viewed the high summits from various sides. They everywhere present the broad low forms illustrated in Plates XXXII and XXXIII, forms of a surface of denudation under conditions of altitude quite different from those which now permit the autogenous tributaries of neighboring streams to attack them vigorously. This mountain type is common throughout southern Siberia, as may be seen in the illustrations of various travels across Asia. One finds it, for instance, in the views of the mountains along the upper Huang-ho,* and it is common in the descriptions of the northern Altai and the Urals. These broad highlands of the Wu-t'ai-shan are believed to represent an early stage of topographic development at a relatively low level, and to be the oldest topographic forms which we saw in the course of our journey.

Northern Loess Basins.†—Coming from Yen-t'ou up the wild canyon of the O-shui-ho, I recrossed the Wu-t'ai-shan south of Ts'a-pu; my comrades, coming from the upper T'ai-shan-ho, crossed the pass between Nan-t'ai and Si-t'ai; and our routes converged at Li-yüan-p'u. Our view southwestward was over a widening expanse of low hill country. A broad valley bottom lay below at a general elevation of 4,000 feet, 1,200 meters, and from it rose many hills only 1,000 to 1,500 feet, 300 to 450 meters,

*Durch Asien, Dr. K. Futterer, vol. 1, Plate 28.
†Atlas sheets C I, B I, C II, and B II.

A



B

A. Five miles west of the village of Wu-t'ai-shan, atlas sheet D I, pass across main Wu-t'ai range, altitude 7,650 feet. General view looking north, showing modified surface derived from that of the Peï-t'ai stage. The mantle of saplite which formerly covered the fresh rocks has been largely removed, chiefly by wind, and residual fragments are scattered about the surface. The pagoda is said to have been built during the reign of Ta-ming, about 500 years ago.

B. Summit of Nan-t'ai, atlas sheet D I, altitude 8,100 feet. View looking west over Wu-t'ai range, showing general approach of the surface, which is eroded across inclined strata of Wu-t'ai schists, to the ancient Peï-t'ai peneplain.

A

B

A. Pass in the Wu-t'ai-shan, 3 miles southwest of Ts'a-pu, atlas sheet C I, altitude 6,500 feet. Level profile in foreground is a surface of soil believed to represent a valley level of the T'ang-hién stage. Beyond are summits of the Wu-t'ai-shan which are 2,000 to 3,500 feet higher.

B. View taken half a mile north of the pass, A, showing character of residual material exposed in gulches now developing in the slopes in consequence of general deforestation of the region within a century and a half.

high. On our right the principal range of the Wu-t'ai rose imposingly against the western sky, but in the remote distance, west by south, it sank away to the inconspicuous ridge at Hin-k'ou. On our left the southern spurs of Nan-t'ai reached as a high range toward the Chï-li-Shan-si divide, with which they form the western end of the Ki-chóu-shan, the highland through which the T'ai-shan-ho winds its deeply sunken channel. The lowland between the ranges was like a deep bay, at the head of which we stood, and which widened beyond our vision. It was the embayment of the northern Loess Basins.*

The descent from the leveled pass of the Wu-t'ai-shan to Li-yüan-p'u was very steep for 1,500 feet, 450 meters, and on rock; below the rock-scarp the ravine was filled with a steep alluvial cone, and it was clear that the intermittent brook was gathering more detritus from above than it could handle below.

When we had descended to the valley, the general view was lost and local details became important. The Huang-t'u formation of loess and gravel overspreads the valley floors. Where torrents run in the rainy season they cut channels, whose vertical walls are of loess while their beds are of coarse shingle (Fig. A, Plate XXV). Elsewhere the waters spread in extraordinarily wide floods, and the precious loess soil which they carry is caught in inclosures of stone walls (see panoramic view, atlas sheet A III). The Huang-t'u curves up and onto the mountain spurs with a characteristic tangent profile, but is cut away in the ravines. Tattered remnants of it cling here and there in strange situations, and challenge alike the advocate of wind or of water as the agent of loess distribution, for neither may account readily for what he finds.

The valley which we entered at Liu-yüan is triangular, having one acute angle at the northeast, where it branches in autogenous fashion; a second angle at the western pass, Ts'ai-shï-ling, where the low divide is covered with Huang-t'u, and the third at the southeast, where the Shï-t'ou-ho enters the canyon that leads to the T'ai-shan-ho. This triangular valley is the northeastern loess basin, the Shï-t'óu-ho or Tóu-ts'un basin. Before leaving it we must note the occurrence of the Huang-t'u in the high valley east of Liu-yüan, 1,200 to 1,500 feet, 375 to 450 meters, above the basin. This valley lies behind a low range of hills and is reached by a deeply cut canyon, which has diverted its drainage from the original south-easterly course (see the common margins of atlas sheets C I and D I).

From Tóu-ts'un to Wu-t'ai-hién the way lies across the second loess basin, a double valley without outlet. The hills between the two depressions are buried in the Huang-t'u, which floors the lowland. Sections of

* This region is well described by von Richthofen in China, vol. II, pp. 369, 370.

the Huang-t'u in the eastern of the two show interstratified peaty layers, and the valley is drained by a loess canyon to the western one. The western has no outflow. Streams entering it are carried in artificial raised canals to a reservoir, and the waters are used for irrigation. At the natural outlet on the southeastern side the Huang-t'u fills an old channel, as may be seen in the deeply sunken road leading to the T'ién-hua coal-mines; but the dam which closes the valley against the present drainage is the alluvial cone of a mountain brook descending from the southwest. At present the brook discharges into the basin, but at any time it may take the more natural course down the valley.

The loess basin of Wu-t'ai-hién, the third in the series, is the valley of the Sing-ho and its tributaries. It conforms closely to the valleys of erosion, corresponding with their broader sections; yet it is not simply a valley widened in the softer slates and aggraded above the canyon in harder limestones, as one might at first sight suppose. Its peculiarities are apparently effects of warping.

The floor of Huang-t'u, in the body of the basin, has an elevation of about 3,500 feet above sea; the surface sweeps up on the mountain slopes irregularly, but several hundred feet higher; upstream it follows the valley; downstream the Huang-t'u covers the northeastern slope of the canyon and also fills a broad valley, which is southwest of the canyon and separated from it by a ridge 1,100 feet, 335 meters, high. The Huang-t'u covers the summit of the ridge and extends to the windgap at the southeastern head of the valley. The difference of level of the Huang-t'u surface in the entire basin is 1,200 feet, 375 meters, and it is highest on the southeastern side. This is in large measure an effect of eolian deposition. The depth of the Huang-t'u varies from a feather edge, where it is wasting away from a mature surface on which it was deposited, to something more than 200 feet, 60 meters, as appears in the deepest loess canyons.

The drainage of the Wu-t'ai-hién basin is peculiarly arranged (see Fig. 57). The course of the Sing-ho, AB, is directly southeast, but like that of other rivers of the district, it is from the wide basin into a narrow canyon. Of the four streams which join it on the west bank, the northern one, CD, follows the course of a normal tributary, but the others, EF, GH, and IJ, flow in the opposite direction. IJ once continued around the end of the ridge that divides it from the Sing-ho, while now it is diverted through the remarkable gorge at J shown in the section, Fig. 38, which expresses the intricate structure. The diversion was accomplished on a vertical zone of soft red shale. Recognizing in this northward-flowing stream one which has been inverted, we find its former channel in the

wind-gap at its head, I. It seems to be clear that there was a river, CGI, which formerly flowed parallel to the Sing-ho, but has been inverted by an upwarp along MN, resulting in the canyon of the antecedent Sing-ho and the diversion and inversion of its weaker neighbor.

Another anomaly of the Wu-t'ai basin is the fact that it is invaded from the southwest by a branch of the Hu-t'o-ho, KL, which cuts in two the ridge between it and the Tung-yü basin. This is a case of growth of a brook through a divide along the strike of a zone of soft slate; but it calls attention to the fact that a surface like that east of the divide, having a gentle slope and being composed of the porous Huang-t'u, is a very

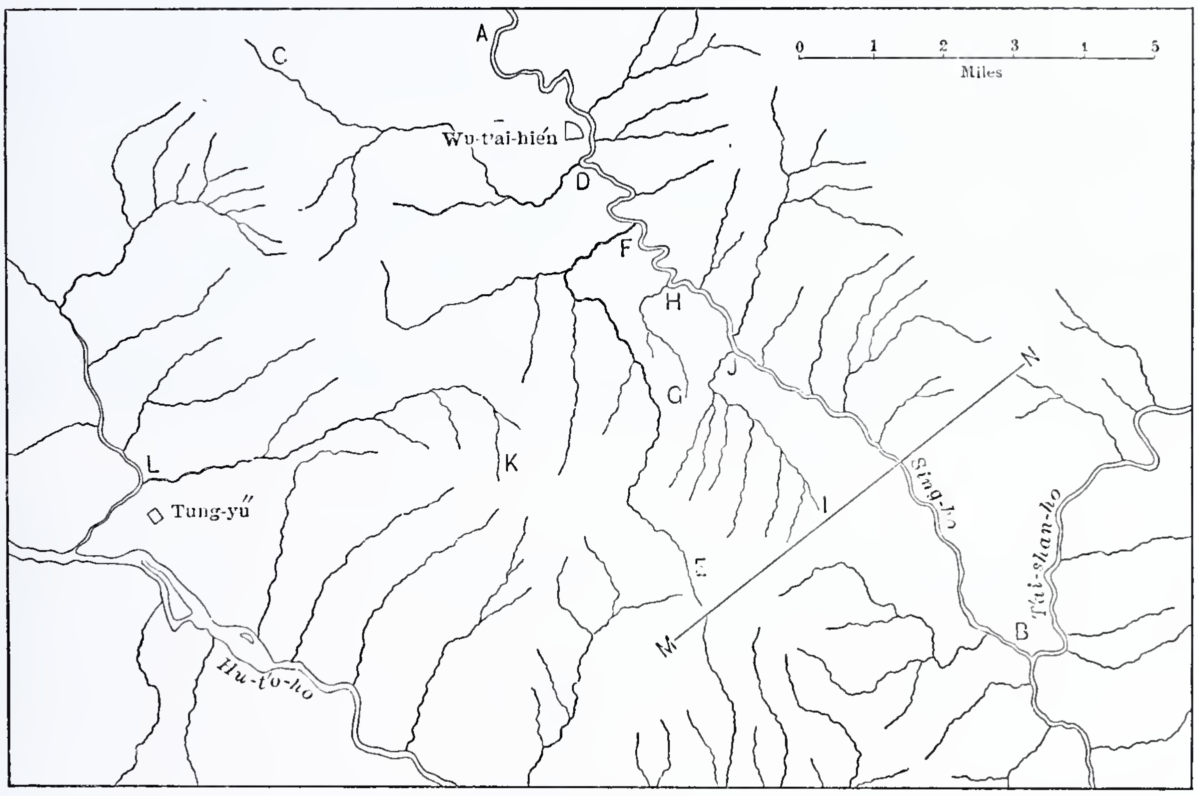


Fig. 57.—Map showing arrangement of tributaries to the Hu-t'o-ho and Sing-ho, near Wu-t'ai-hién, Shan-si; reduced from the surveys by Sargent, atlas sheet C I.

absorbent one. No stream forms on it, and unless it be gullied from a lower level it may, in appropriate situations, be an area of accumulation by wind drift. Had the Huang-t'u surface not been an absorbent one, the Sing-ho might have contested the divide it has now lost to the Hu-t'o-ho.

The Tung-yü loess basin is a simple river valley directly parallel to that of the Sing-ho and Shï-t'ou-ho, from the Wu-t'ai-shan to the T'ai-shan-ho. The original small stream is now joined by the Hu-t'o-ho, the master river of the region, which comes through a rock gap west of Tung-yü. The fact that the Hu-t'o-ho at this point crosses a ridge, in a relatively narrow gorge of youthful aspect, in a course directly opposed to the south-

westerly courses of the older streams of the region, indicates that even the master stream has been diverted to its present channel. The course which it once had was probably through the pass, Shï-ling, to the Fön-ho.

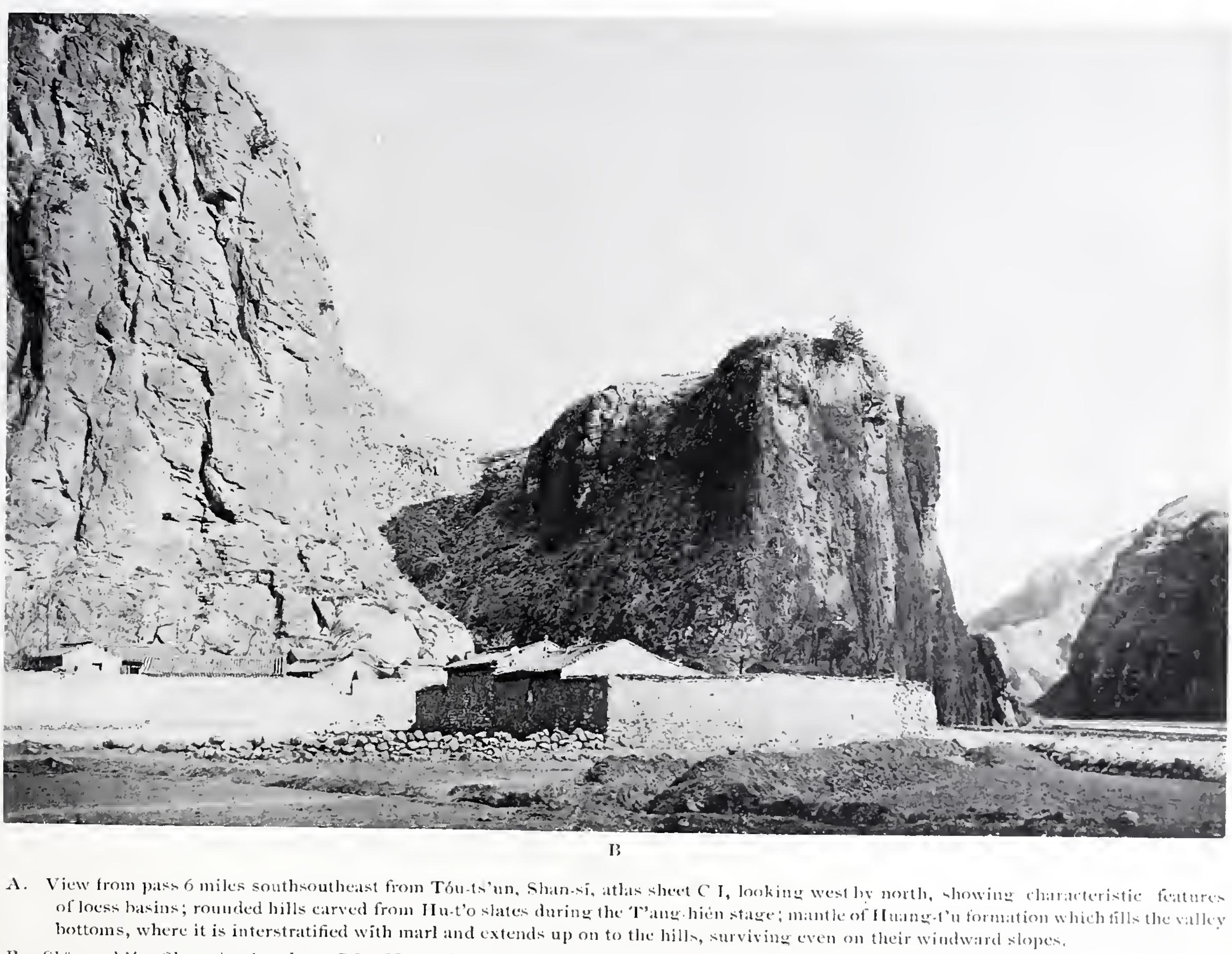
The fifth loess basin is that of Hin-chóu. It may best be described as an oval, intermontane plain, of the Huang-t'u formation, about 25 miles, 40 kilometers, long and 10 to 18 miles, 16 to 29 kilometers, across. On the southwest, northwest, and northeast, low ranges of gneiss, schist, and slate inclose it in an arc of hills, through which are several broad passes. Across the southeastern side stretches the nearly straight scarp of the towering Ki-chóu-shan, a magnificent wall, 3,000 to 4,000 feet, 900 to 1,200 meters, high. The plain of the basin is very fertile and densely populated, ninety villages being in sight from a commanding peak. While sharing with the other loess basins the common characteristic of being floored by the Huang-t'u formation, the Hin-chóu differs markedly in many respects from them. Its area, roughly computed at 350 square miles, 900 square kilometers, is more than twice that of the other four combined. Its plan is an irregular oval, unlike an erosion form, and longest from northeast to southwest; whereas the others resemble river valleys and are longer from northwest to southeast. From each of them a canyon has been cut southeastward, but from the Hin-chóu basin the large river, the Hu-t'o-ho, has been diverted northeastward to the valley of a minor stream. Southeast of the Hin-chóu basin is the great fault-scarp of the Ki-chóu-shan, a unique feature in this region, though only the northeastern one of several analogous scarps. And where the Ki-chóu-shan sinks away there is a pass, the Shï-ling, which is widely covered by the Huang-t'u formation and leads to the still larger basin of T'ai-yüan-fu.

These differences between the Hin-chóu and the four smaller basins find their explanation in the relative effects of two processes to which the basins owe their characters, namely, erosion and warping. In the smaller basins the effects of erosion are more apparent, and it is difficult to recognize the superimposed effects of warping. In the Hin-chóu basin warping and faulting have produced a form on which the features of erosion are subordinate details.

This description of the northern loess basins has thus far been directed to bringing out the distribution of the Huang-t'u formation and the arrangement of streams. Another aspect of the region is the character of the relief, and I commend to the student of physiography the expressive contours sketched by Sargent. (Atlas sheets C I, C II, and B II.)

Outside of the Huang-t'u formation, which has its own peculiar forms of slope and canyon, the relief on the older rocks seems, at first sight, to present two principal aspects: that carved from the Pre-Cambrian schists and slates, and that sculptured in the Sinian limestones. The hills which

A



B

A. View from pass 6 miles southsoutheast from Tóu-ts'un, Shan-si, atlas sheet C I, looking west by north, showing characteristic features of loess basins; rounded hills carved from Hu-t'o slates during the T'ang-hién stage; mantle of Huang-t'u formation which fills the valley bottoms, where it is interstratified with marl and extends up on to the hills, surviving even on their windward slopes.

B. Shï-pan-k'óu, Shan-si, atlas sheet C I. View of the canyon of the T'ai-shan-ho in Cambro-Ordovician limestone, just below T'ién-hua coal field; typical limestone canyon of Fön-ho stage; the cliffs are about 600 feet high.

rise from the loess basins consist chiefly of slates and have monotonous, mature profiles. By reason of their maturity they take their place in relative age with the high spurs, which represent the old valleys of the Ts'ing-shui-ho and T'ai-shan-ho, designated by *b*, Plate XXX; they have not, however, been cut by younger canyons as that surface has been. They are well shown in Fig. A, Plate XXV, and Fig. A, Plate XXXIV.

On entering the limestone district, southeast of the loess basins, one is impressed with the wild, youthful aspect of the canyons (Plate XX and Fig. B, Plate XXXIV), and one might conclude that here, also, there was but one phase of topography represented. Thence it would be but a short step to the conclusion that the mature topography of the soft slate hills and the young topography of the limestone mountains were of one and the same stage of development, and differed only on account of the unequal wear of the rocks. But such is not the case. In the Yau-t'óu district and generally over the Ki-chóu-shan, one may recognize a surface of moderate, mature relief, which corresponds with that of the slate hills, and within it are cut the deep, young canyons (Plate XXXV). The parallel with the stages of the Wu-t'ai-shan (*b* and *c* of Plate XXX) is complete, except that the canyons in the limestone are narrower, as they should be in the harder rocks.

This parallel is sustained if we trace the topographic forms in the ridge south of Wu-t'ai-hién, west of the Sing-ho. Over its western slope is the heavy mantle of Huang-t'u, which extends to the crest; there, 1,100 feet, 335 meters, above the river and cut off by its canyon wall, are partly bare hills of slate, exhibiting the mature surface of the hills of similar rock down in the basin (Fig. A, Plate XXVI). Tracing the ridge southward, we follow the mature surface on to the Sinian limestone, where, though the relief is somewhat greater, the forms are unmistakably the same. Thus we here find the Huang-t'u overlying an old topography, which is common to the soft slate and hard limestone, and is trenched by the younger canyon of the Sing-ho.

Among the mountains we crossed in Chï-li and Shan-si, there is no height so striking as the Ki-chóu-shan, seen from the Hin-chóu basin. The great Wu-t'ai-shan, though 4,000 feet, 1,200 meters, higher, is like the top of a dome—too huge to be overlooked; there is no point from which its magnitude can be appreciated. But the Ki-chóu-shan is a wall, which, rising full 3,500 feet, 1,000 meters, from the basin plain, adds all the advantage of contrast to its imposing height.

The face of the Ki-chóu-shan is unlike any topographic form we had seen in China—straight, steep, and but slightly eroded. It is representative of those great scarps of the Ho-shan, Hua-shan, and Ts'in-ling-shan, which we recognized as evidences of comparatively recent normal faulting.

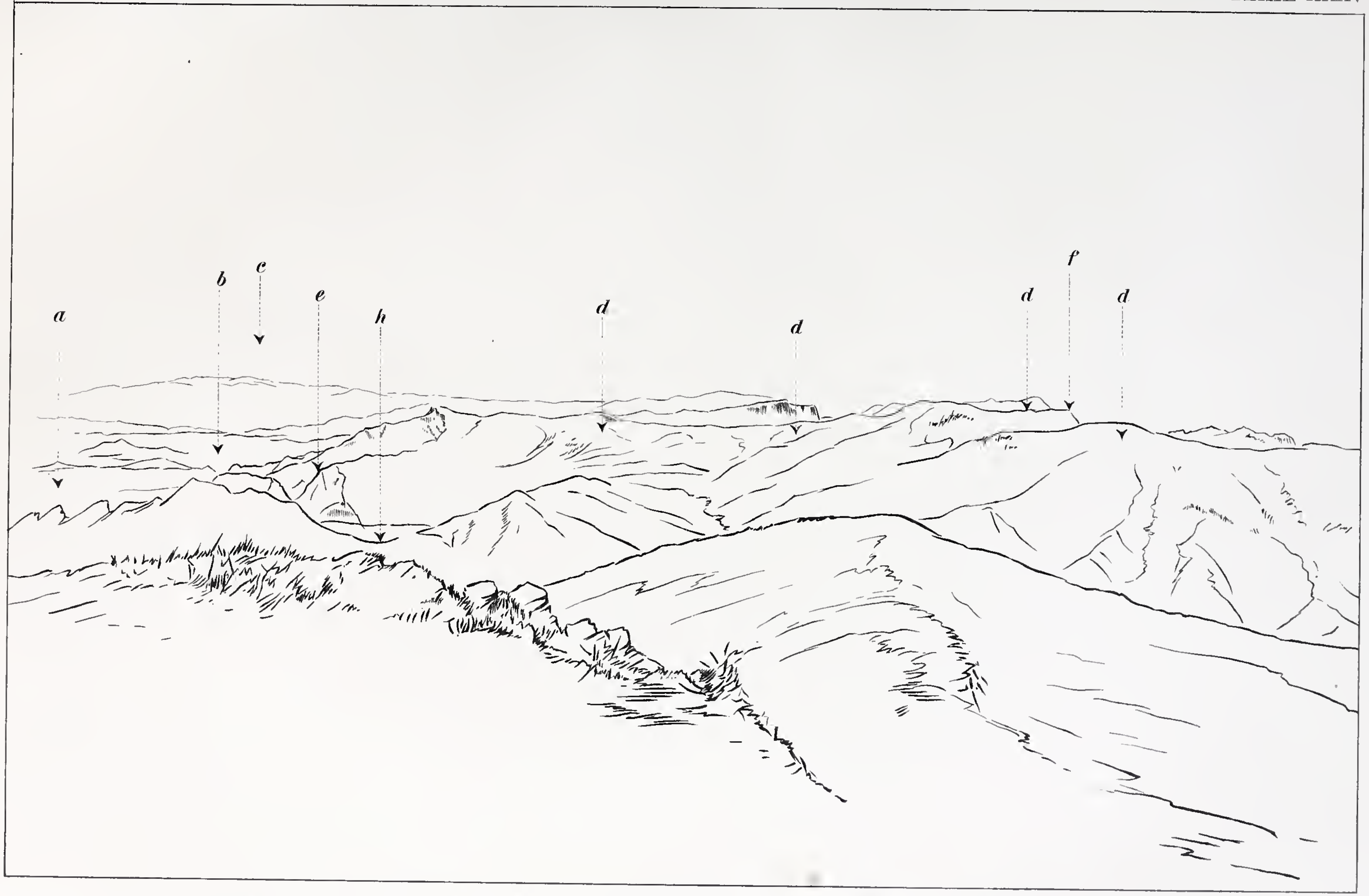
I quote from my notes as follows:

The face of the range southeast of the Hin-chóu basin (the Ki-chóu-shan) was veiled in dust until to-day. We approached it from Fang-lan-chön, at a point about S. 75° E. from Ting-hiang-hién, where a well-established trail leads over the divide. Here the range is high, with summits of 6,000 feet or more. Its face is cut by many ravines 1.5 miles long, more or less, from the head of each alluvial cone to the crest. The intervening spurs just here have an average slope of 20°. They are gentler and longer toward the gap of the Hu-t'o-ho, 3 miles east, and steeper and shorter further west. The detailed profile varies in each ridge according to the texture of the rocks, gneiss, granite, shale, and limestone, but the line along the tops of the lower cliffs is remarkably even. Each ravine debouches upon an alluvial cone, and the successive cones are confluent. They rise 1,000 feet above the plain and have a radius of about 2 miles. Their material consists in part of coarse shingle, which is mostly limestone with some granite and gneiss, and in part of residual soil, that is caught in terraces and cultivated. Westward the alluvial cones grow shorter and in 3 miles nearly fail. The face of the range is notably steeper. The long spurs are wanting. The shorter spurs are very steep, of uniform front to a line, and end in a triangular facet which is but slightly gashed. These are features of a fault-scarp upon which there has recently been movement.

The facts just noted form the culmination of various evidences of a decided upwarp in the range south of the several loess basins, together with relative or absolute downwarp along their common axial line. The evidence was lacking east of Wu-t'ai-hién, was first observed in the district of deep loess canyons west of the Sing-ho in the Wu-t'ai-hién basin, appeared more emphatically evident as a tilted topographic surface west of the Tung-yü basin, and is most obvious south of the Hin-chóu basin. The upwarp and the downwarp are recognized in the relative positions of surfaces of a mature phase of topography, which has developed wide valleys in the weak rocks, and to a less degree in the limestones. This topographic phase is seen in the basins at altitudes of 2,500 to 3,000 feet, in the Yau-t'óu and the Ki-chóu-shan at altitudes of 4,500 to 6,000 feet, and may be traced on continuous spurs descending from the higher to the lower occurrences. The evidences of tilt are seen also in accelerated drainage effects in all streams flowing northwest; whereas the southeasterly courses of the greater rivers appear to be antecedent valleys, which have deepened to canyons in the development of the upwarp.

The view of the upper surface of the Ki-chóu-shan at an altitude of about 6,000 feet is shown in Plate XXXV, which was sketched on the triangulation point south of Chung-hua looking northeast.

Our course lay through the depression of the loess basins and we saw the mountain ranges southeast of them only from high summits, which we occasionally ascended in the progress of the work. So far as we could thus observe, it was a broad belt of mountains, which showed little difference in altitude for 20 miles, 30 kilometers, or more, and beyond which our view did not extend. The forms of the mountains were those characteristic of the Sinian limestones in the nearer view, with equally elevated peaks which suggested the Pre-Cambrian Wu-t'ai schists or T'ai-shan gneiss in the further distance. It is probable that the broad section of T'ai-shan gneiss which we passed on the Sha-ho, and possibly some of the



View of the summit of the Ki-chóu-shan, Shan-si, from peak south of Chung-hua, atlas sheet B. II; looking northeast. a = Hin-chóu basin, b = Tung-yü basin; c = Wu-t'ai range, Peï-t'ai stage; d = profiles near Peï-t'ai stage; e = eroded fault scarp; f = cliffs overlooking canyon of Hu-t'o-ho.

younger Pre-Cambrian rocks, extend southwestward in an anticline, and that the syncline of Sinian strata which forms the Ki-chóu-shan, and which ends southwest of the T'ai-shan-ho, is limited to a width of 15 or 20 miles, 25 or 30 kilometers, northwest to southeast.

The valley of the Hu-t'o-ho northeast of the Hin-chóu basin lies between the Wu-t'ai-shan and the range which forms the outer border of the high plateaus of Mongolia. Our topographic surveys did not extend up the river beyond Hin-chóu, but I took some notes in a rapid trip to Tai-chóu and across the Wu-t'ai-shan to Tung-yü, of which I quote the following:

At Hin-k'ou a ridge of quartzite extends across the valley from east to west and reduces it to a narrow water-gap. The quartzite is dark red, much jointed, and cut by basic green dikes. It belongs to the lower part or at the base of the Hu-t'o system, and may be seen dipping gently 10° to 30° toward the northwest. Opposite Yüan-p'ing are craggy hills, consisting principally of gneisses of the T'ai-shan complex, and on their eastern slope are strata of the Hu-t'o system dipping southeast 30° to 40°. Thus the southwestern end of the Wu-t'ai-shan appears to be sculptured from a syncline in rocks of the Hu-t'o system, and the gneiss comes up from under them on the northwest.

Between Yüan-p'ing and Kwo-hién we passed several caravans carrying coal from points on the Yang-wu-ho, and the escort reported mining at five or six places on the road to Ning-wu-fu, at intervals of about 10 li, or 3 miles, apart, the nearest being 15 or 20 miles from Yüan-p'ing.

The mountains northwest from Kwo-hién exhibit a deeply eroded front, locally precipitous toward the top and sending out spurs into the plain below. Alluvial fans are confluent and extensive along the base of the range, rising approximately 1,000 feet above the plain, or one-fourth of the total height of the mountains. The outcropping cliffs present faces of limestone, probably Sinian, dipping apparently gently northwest. The structure of the range appears, however, to include folds or faults, which influence the elevation of these outcrops and suggest that the plateau is not one of simple flat strata. The valley is wide and flat, the river flowing through a flood-plain which is aggraded with gravel, sand, and loess. The effects of transportation by water are obvious in the wide distribution of the gravels, and the influence of the wind in sorting and distributing the finer materials is apparent in the sweeping clouds of dust and in extensive areas of dunes.

We left the Hin-chóu basin by the main highway across the Shï-ling, and went up the deeply sunken wagon track over the surface of the Huang-t'u. In order to avoid clouds of dust in the canyon of the roadway, and gain a freer outlook, we took the footpath which follows the brink of the road, often 100 feet above it. On both sides stretched the smooth, even surface of the loess, which, being quite steeply inclined, is cut by many deep, parallel canyons. As we approached the summit we found the bed-rock of Sinian limestone outcropping in limited exposures. There is a long flat at the top of the pass and then a gradual descent to the basin of Huang-t'u-chai, a wide level scarcely a hundred feet lower, which overlooks the tributary of the Fön-ho. The level is composed of the

Huang-t'u formation, which here, as elsewhere, extends to the adjacent hills by its peculiar tangent curve; the same covering appears extensively on the summits of the hills, though eroded from their steeper slopes. From all higher levels the Huang-t'u is being eroded and redistributed by the torrential rains, the gravels being spread as alluvial cones upon the surface of the older Huang-t'u deposit, and the loess being carried out further into the plain and incorporated with it. The winds which sweep the bare surface during the seasons of drought and cold carry back some part of the loess and in a measure maintain the fringe that rises onto the slopes, but on the whole the process is one of denudation, and the mature forms of the topographic surface beneath the Huang-t'u are reappearing.

The basin of Huang-t'u-chai lies immediately south of the Hin-chóu basin, and is connected with it by the continuous surface of the Huang-t'u formation across the Shï-ling Pass. Southward it opens as a valley of a branch of the Fön-ho into the basin of T'ai-yüan-fu, and forms a connecting link between the latter and the Hin-chóu basin. Its character is rather that of a wide river valley than of a simple downwarp, it being relatively narrow and branching. We shall see that probably both erosion and warping have been effective in producing its present aspects.

The principal branch of the Fön-ho, which flows through the basin of Huang-t'u-chai, has cut a wide channel some 300 feet, 100 meters, below the level plain of the basin, and canyons of unusual narrowness are rapidly growing back into the Huang-t'u formation. The highway follows down the sides of one of these, giving rather startling opportunities to look into its depth. In the bottom of another the underlying Sinian limestone is found, and the thickness of the Huang-t'u may be determined to be about 230 feet, 70 meters. In all the bluffs in which the formation is thus clearly exposed, one may see indistinct but definite stratification in beds that are usually several feet thick. The strata are not distinguished by a difference of composition, but appear to be defined by a horizontal parting in homogeneous material. Throughout the prevailing fine loess, which makes up the greater part of the formation, there are beds of gravel, the wash from the nearby hills. Near Huang-t'u-chai, a temple, which is said to have been built about 350 years ago, stands at a distance of about 100 meters from the neighboring stream, on a bluff 80 feet, 24 meters, in height. The cliff of loess has receded until the temple is in danger (illustration, atlas sheet B III) and we may assume that the building formerly was much further removed from the edge of the canyon. If we admit that at the time of its construction the bluff was near the present position of the river bed, we should have a maximum retreat of 100 meters in 350 years. The time and distance in this estimate are both approximations, but they serve to give some idea

of the rate of the process, which is of much interest in the study of the physiographic history of the region. The conditions of retreat are very favorable at this point, since the work of the stream and the activities of the natives in widening their fields in the valley have combined to hasten the recession.

The brooks which occupy this old valley are comparatively insignificant. Their drainage area is circumscribed by the summits of the immediately surrounding ridges. They are autogenous streams, occupying the valley of a once much larger river, probably of the Hu-t'o-ho.

Below Huang-t'u-chai the route follows the broad valley of the northern branch of the Fön-ho and reaches the city of T'ai-yüan-fu, which lies partly within reach of the floods of the river, partly on the low slopes of Huang-t'u, stretching toward the eastern hills. Off to the northwest the valley is bounded by a bold escarpment of Sinian limestones, at which the river emerges from a picturesque canyon. The view from the summit of the escarpment discloses a deeply cut plateau, which exhibits an upper, maturely eroded surface traversed by youthful canyons.

The basin of T'ai-yüan-fu may be called the sixth and most southern of the northern loess basins. It is connected with the Hin-chóu basin by the old river valley of Huang-t'u-chai, and the two lie with their major axes nearly parallel and *en échelon*, the southern one being offset to the southeast. This is a characteristic of the structural forms of the great arc of normal faults to which these downwarps belong.

The T'ai-yüan-fu basin is much larger than any of those to the north of it. It is 70 miles, 110 kilometers, in length from northeast to southwest, approximately 25 miles, 40 kilometers, across, and has an area approaching 2,000 square miles. Had we detailed maps of its surface and of the surrounding mountains, we would no doubt find expressive features in which to read the details of its history; but the general phenomena, so far as we were able to observe them, do not appear to differ from those of the Hin-chóu basin. Along the northwestern margin of the plain the mountains rise with a moderately steep, but nowhere precipitous, face and are cut by well-developed valleys at right angles to their trend. Details of form vary with the character of the limestone, shale, or sandstone, but in general a similar topographic phase extends from the plain to the summits of the hills and there is a unity of development in the slope which contrasts with the younger transverse ravines. Low hills forming the points of the spurs just above the plain are similar in character to higher hills which rise from the upper slopes. The whole presents the aspect of a surface developed under uniform conditions—that is, at a common altitude—and which has since been warped, so that some parts of it now lie along the margins of the plain, while other

parts of the surface rise several thousand feet higher. The slope is steep, however, as compared, for instance, with that by which a similar old surface of erosion sinks beneath the plain near Tang-hién on the western side of the Great Plain in Chï-li, and there are no islands, the summits of buried hills.

We did not see the embayment of the T'ai-yüan-fu basin west of Fön-chóu-fu, but crossed from the latter city southeastward to the point at which the Fön-ho escapes from the basin. We thus approached the northern end of the Ho-shan and traced the rise of the range from the relatively low hills that represent it near P'ing-yau-hién to the magnificent scarp which characterizes it east of Ho-chóu. In this distant view the range reminded me of the Ki-chóu-shan. Like the latter, it seemed to originate in a warped surface, and to gain its greatest altitude in the development of a normal fault-scarp growing out of the warped surface. If the observations which we thus made on the northwestern and southeastern sides may be trusted to apply equally to the east and west portions of the basins of T'ai-yüan-fu, this great depression represents an extensive downwarp, about the margins of which we see in general the remnants of the preceding topography, tilted toward the basin and dissected by the autogenous streams that had grown upon the warped surfaces. It is clear that such a downwarp must be filled by detritus from the adjacent hills, and that it is possible that its development may include an episode of lake history. Von Richthofen maps the loess of the basin in part as lake deposit, and places it among the depressions which have contained a salt lake. We were unable to make any investigations which might bear upon this point.

The outlet of the Fön-ho from the basin of T'ai-yüan-fu has the look of a young river valley. It is at the point of a sharp V between the foothills of the Ho-shan and those of the O-shan, which appear to be cut from sandstones and shales of the Shan-si series. On the right bank of the river a conspicuous pagoda crowns a hill 500 feet, 150 meters, high and dominates the view. The plain slopes rapidly to the exit, like an alluvial cone of fine material, as though the upper valley were overfilled with detritus. The current of the river is swift. The rock gorge which the river enters is open, and the adjacent slopes are comparatively gentle as far as Liang-t'u-chön.

The canyon of the Fön-ho, Ling-shï to P'ing-yang-fu (see map, Plate XXIII).—The comparatively open valley of the Fön-ho above Liang-t'u-chön is replaced as we approach Ling-shï by a canyon which deepens to about 400 feet, 120 meters, yet has a relatively wide, aggraded bottom. The canyon walls are not conspicuous, but are obviously steep in distinction to the higher slopes, which widen out rapidly to the loess-covered

hills above. Between Ling-shï and Ho-chóu the channel of the river is probably very narrow, at least in some stretches, for the highway, which would otherwise naturally follow it, is carried over the two high passes, the Si-sin-ling and the Si-yau-ling. The difficulties which these present to the heavy traffic on this principal route through the province are so great that nothing short of an impassable gorge would seem to justify the course the road takes.

As we cross the pass there are many views over the wide hill country above the Fön-ho, westward to the distant O-shan and eastward to the nearer and imposing Ho-shan. The Huang-t'u formation extends over the hill summits, and rises in long terraced slopes to the base of the Ho-shan (panorama, atlas sheet A III). One is reminded of the surfaces of the warped lake deposits to be seen in the southern Sierra Nevada, where the once horizontal surfaces exhibit differences of elevation of as much as 1,200 feet, 365 meters. It seems apparent that, with the relative upthrow of the great fault-scarp of the Ho-shan, the adjacent valley segment on the downthrown side has been inclined to a slight degree in the upward movement.

Beneath the Huang-t'u is a mature topography cut in the Shan-si coal series. The rocks are frequently exposed at the bottom and in the sides of the loess canyons. Von Richthofen's impression that the Huang-t'u formation might have a thickness of 1,500 feet or more was erroneous. It is an uneven mantle which once covered the entire surface, but which is probably not more than a few hundred feet thick. We recognize in these relations of the Huang-t'u and the underlying topography the same conditions that we saw in the hills about Wu-t'ai-hién and the Hin-chóu basin, but with a difference: In those localities the Huang-t'u occupies a depression, and has been preserved from erosion or added to; in this district the Huang-t'u is elevated and is being rapidly eroded.

A physiographic study of the fault-scarp of the Ho-shan was one of the attractions of the region which we were obliged to pass by. We saw the scarp from a distance of 10 miles, 16 kilometers, or more, and could recognize that it was very steep and deeply gashed by ravines which had grown at right angles to the face.

In the vicinity of Chau-chöng the Fön-ho flows in a valley, which has a canyon only about 80 feet, 24 meters, deep, in rocks of the Shan-si series, bounded above by bluffs of loess. Whereas further north, near Ling-shï-hién, the valley suggests that of the Monongahela above Pittsburg, the shallow canyon and rolling upland in this section remind one of the Ohio near Cincinnati.

Approaching P'ing-yang-fu, the highway lies chiefly in the alluvial plain of the Fön-ho, a highly cultivated, irrigated district, which widens

to a basin several miles across. The alluvium resembles the Huang-t'u formation in texture, color, and structure, but it is horizontally bedded. The valley is bounded by bluffs of Huang-t'u, rising to an upland 50 to 80 feet, 15 to 24 meters, above the present flood-plain, which is continuous with that of the high passes south of Ling-shï, and represents the same stage of topographic development.

Considering a north-south section from the basin of T'ai-yüan-fu to the plain of P'ing-yang-fu, we note that the surface of the Huang-t'u formation rises from the basin, where its altitude is about 2,750 feet, 840 meters, above sea, to about 4,100 feet, 1,250 meters, between Ling-shï-hién and Ho-chóu, and sinks again to about 2,600 feet, 800 meters, at P'ing-yang-fu. The buried surface beneath the Huang-t'u conforms nearly to the same differences of elevation. It is a surface of mature erosion and was once nearly flat. The Fön-ho flows in a canyon, which is deepest where the Huang-t'u and the buried topography lie highest; and the Huang-t'u is being invaded by many canyons of vigorous youthful growth. These facts combine to demonstrate the existence of an arch or upwarp, which trends across the valley, probably northeast to southwest. The movement is a comparatively recent one, younger than the Huang-t'u formation, and the Fön-ho, being antecedent to the upwarp, has cut a canyon in maintaining its course. A little further south it was not so successful.

At P'u-chóu-fu we met Mr. A. R. Bergling, a missionary residing at Han-chöng on the Huang-ho, and were told by him that above Han-chöng the Huang-ho flows in dangerous rapids through a rocky gorge. It is possible that this canyon, like that of the Fön-ho, is cut across the northeast-southwest upwarp just described.

The Fon-ho below P'ing-yang-fu.—The valley of the Fön-ho south of P'ing-yang-fu is sunk in the Huang-t'u formation, the bottom of which does not appear in sections along the road. There are many deep cuts where the road descends to or rises from the gorge of one of the tributaries of the Fön-ho, and usually one finds at these points beds of coarse cobbles, many of them as large as a man's head, interstratified with the fine, vertically cleaved loess. These are obviously deposits of the lateral streams from the adjacent high mountains, and they indicate that the Huang-tu formation was built up under conditions favorable to at least occasionally vigorous water transportation. At a point about 15 miles, 24 kilometers, south of P'ing-yang-fu a bed of marl is interstratified with the loess. The marl is about 30 feet, 9 meters, in thickness, of greenish white and buff color, and contains minute, very fragile shells which we were unable to preserve. The surface of the marl is cut away by a channel of erosion which is filled with loess, and beyond this point the exposure was obscure. We have here a record of deposition in a fresh-water pond which was

drained and, after the bottom had been partly eroded by a stream, covered by the general deposit of loess.

At its junction with the Kü-ho, the valley of the Fön-ho is a wide flood-plain, the flat surface of a modern loess deposit. In this broad plain the Fön-ho changes its course and flows westward to the Huang-ho; but southward, in the direct line of the upper river, is a low pass by which it formerly continued to P'u-chóu-fu. The reason for the diversion is the growth of a very recent upwarp, across which the stream for a long time held its way, until it was captured by the tributary of the Huang-ho, whose course it now follows.

The evidence of the upwarp is found in the character of the region which extends east and west, south of the diverted Fön-ho. It is a flat summit about 1,200 feet, 370 meters, above the river, completely covered with loess, on the northern slope of which there is a group of loess canyons of extremely recent development. They extend to the summit of the ridge, but have not yet crossed its even sky line. In the upper cliffs one may see, interbedded with the loess, a band of greenish gray marl, a stratified deposit which could not have been laid down in its present position. Around the western end of this ridge there extends a broad valley, which is probably 250 feet, 75 meters, above the present level of the Fön-ho, and is filled with alluvium. The alluvium consists of loess and stream gravels, and in every way corresponds with the Huang-t'u formation. It is characterized by especially abundant snail shells. The road crosses the pass without appreciable climb, and descends very gently southward. A wide plain opens toward the south, and across the plain runs an old river bed, following the bases of alluvial cones and dividing downstream after the manner of distributaries of a delta. The channel is occupied by a rivulet, and is now floored by sandy clay about 100 meters in width. From this clay salt is obtained by digging shallow holes, in which brine rises.

The broad flat top of the ridge, the vigorous but very youthful canyons in the loess on its slope, and the abandoned river channel in direct line with the Fön-ho, appear to leave no question that we have here an instance of warping, which has produced an elevation of 1,200 feet, 370 meters, which was so rapid as to divert the river, and is so young that the steep slopes have not yet been denuded of the soft Huang-t'u.

In the discussion of the structural geology of southern Shen-si, the valley at the northwest base of the Föng-huang-shan was described and the face of the range was discussed as a mature fault-scarp. In this description of the physiographic features it will suffice to repeat that the face of the range is steep and characterized by those triangular facets, as terminations of the lower ridges, which are taken as direct representatives of the normal fault-plane. It was also stated that, as we went southwest-

ward along the fault-scarp, it gradually diminished in throw and ultimately passed into a warped surface which trends southward. It is thus that we approach the valley of the Huang-ho.

We visited the city of P'u-chóu-fu, which lies in the flood-plain of the Huang-ho and had recently suffered from a rise of the river, and thence made our way southeastward to the ferry across the Huang-ho at Tung-kuan. On leaving P'u-chóu-fu the way continues for several miles over the low flood-plain of the Huang-ho, and then rises onto low river terraces 4 to 10 feet, 3 meters, higher. The village of K'ou-ho was reached in 50 li, about a half day's journey. It is at the base of a bluff consisting of the Huang-t'u formation, which is here composed almost wholly of loess, and which rests on a stratum of very soft sandstone and gravel. The dip of these underlying strata is locally 12° to 18° to the west, but lessens westward until they finally lie flat. The sequence of the strata observed from below upward is sandstone, 15 feet, 4.5 meters, upon the eroded surface of which is deposited gravel, 6 to 8 feet, 2.5 meters, followed by the Huang-t'u formation, 80 feet, 24 meters, to the top of the bluff. Two slight normal faults, probably of very small throw, were observed, the strike being north and south and the hade steep toward the west. This deposit underlying the Huang-t'u formation appears to be an ancient river deposit, which must be assigned to an epoch antedating the accumulation of the Huang-t'u formation in this particular locality.

A mile west of K'ou-ho our road led through a very narrow gulch up to the surface of the Huang-t'u, about 125 feet, 35 meters, above the flood-plain of the Huang-ho. This surface is nearly level and has the characteristics of a river flood-plain. On the north it is bounded by a zone of hills 100 to 150 feet, 30 to 45 meters, higher, which are greatly dissected by well-developed gullies. They either consist entirely of the Huang-t'u formation or are covered by it. Back of these hills the slope merges into alluvial cones and thence into the foothills of the Föng-huang-shan, which rise very gently toward the main range (see Fig. 54). The south slope of the mountains is thus in strong contrast with the northwestern. The latter is precipitous, the former so gentle that one might almost drive a carriage up it. One is a normal fault-scarp, the other a tilted topographic surface upon which the accelerated streams have not yet accomplished any great amount of erosion.

From the terrace about 135 feet, 40 meters, above the Huang-ho, the descent to the river at Tung-kuan is through a sharp steep gulch in the loess. The width of the river's channel at this point, from bluff to bluff, is probably between 2,000 and 3,000 feet, 600 and 900 meters. Extensive mud flats occupy much of the space at the low stage of water

which prevailed when we were there. The fact that houses are built on the bank, 9 to 12 feet above the water, shows that in this broad channel ordinary floods do not rise to that level. On the south side, the bluff of the Huang-t'u formation is 60 to 80 feet, 18 to 24 meters, high. At the base it is composed of sand or very soft sandstone for 20 feet, 6 meters, followed by gravel, 8 to 12 feet, then loess to the summit. The loess is not distinctly stratified and has the usual columnar structure. Ascending to the top of this bluff, one sees the south side of the valley formed by hills of the Huang-t'u formation, which reach an altitude of 300 feet, 90 meters, above the river and extend southward to the foothills of the Ta-hua-shan.

A cross-section of the valley of the Huang-ho from north to south is given in Fig. 54, which is drawn without reference to any exact relation between horizontal and vertical scales, since we have no survey of the valley on which to base a precise representation. It will be seen that at this point the Huang-ho flows parallel to the normal fault, of which the Ta-hua-shan is the upthrown block, and that the valley occupies a position on the downthrown block, which is covered by the Huang-t'u formation to an unknown depth.

To explain the aggraded condition of the valley, we may suppose that the district once stood somewhat lower with reference to sea-level than now, permitting the Huang-t'u to accumulate as an alluvial deposit up to the level which is 300 feet, 90 meters, above the present river bed; and that, in consequence of elevation, the river has now sunk its channel to a position 300 feet, 90 meters, below that surface which it occupied. Or we may, as an alternative, infer that in consequence of greater throw of the fault in the vicinity of Tung-kuan, as compared with some point further east, the bed-rock lies deeper at Tung-kuan than it does to the eastward. Then the river, in developing its course on the downthrown block, would encounter the rock ridge somewhere east of Tung-kuan, but, being retarded, would deposit in its upper course, while cutting a rocky canyon below. As the channel in the canyon was sunk, that in the alluvium would also be lowered. Some color is lent to this hypothesis by the fact that rapids dangerous to navigation are reported east of Tung-kuan. The lower course of the river has never been examined by any scientific explorer, as the road which follows the valley diverges from the stream, presumably in the section which is through the canyon. The exact condition which determines the heavy deposit of the Huang-tu formation at the great elbow of the Huang-ho remains, therefore, indeterminate. It may be a fact bearing upon general movements of the district with reference to the great plains of China, or one determined by purely local warping in the lower valley of the river.

THE DEVELOPMENT OF STREAMS.

Before proceeding to discuss the evolution of topographic forms in historic sequence for the entire region, I propose to take up the growth of the several rivers and to describe each of them in turn, thus obtaining an assemblage of facts which can later be ordered in historic sequence.

The T'ang-ho and the Hang-ho.—These two streams flow in parallel courses from the high mountains of northwestern Chï-li to the Great Plain, and have in any generalized map the directness and simplicity of consequent streams developed upon the mountain slope. But in describing the features along our route it has been stated that in detail they present many facts expressive of a complex history, and a closer analysis shows several successive stages of development. The further discussion may begin with their lower courses in the Great Plain.

Referring to the T'ang-hién atlas sheet, F I, the T'ang-ho may be seen debouching from the mountains of the Ning-shan basin, and flowing between the summits of the submerged hills out upon the Great Plain. Its course is aggraded and determined upon the alluvial plain as are the courses of a river in its delta. In general character the T'ang-ho presents, in fact, an example on a small scale of the rivers which enter the plain, including even the great Yellow river. It takes its course down the slope of the plain, building up its banks after the manner of overloaded streams where the fall is insufficient; but near the foothills, within the area of our survey, maintaining a close balance between filling and corrasion, so that it spreads out in sandy flats and neither lowers nor raises its channel. Its course under these conditions is determined by the general slope of the surface in the practically homogeneous material of the Huang-t'u formation. Were it, in consequence of an uplift, to sink its present channel in the soft alluvium, it would discover a very uneven surface of hard rock beneath, and its valley would be characterized by short canyons in the hard rocks and open basins where the alluvium was still deeper.

The description of the T'ang-ho in the preceding paragraph applies to it as far up as Si-ta-yang. Above that point the southeastern range of the Ning-shan basin is of so continuous and elevated a character as to introduce a seemingly new phase of relations. The Hang-ho, for example, flows within a rather well-defined canyon across the mountains; the wide valley plain and the prevailing cover of the Huang-t'u formation are lacking, and the condition under which the stream took its course across the height is not immediately clear. It is necessary to examine the features with reference to their relative age to reach an understanding.

The Hang-ho flows, as I have said, in a narrow valley which locally has the aspect of a canyon. Never very continuously or narrowly shut

in by walls, it nevertheless is bounded by occasional bluffs, which rise almost precipitously for 100 feet, 30 meters, or more. These give it a somewhat youthful aspect and would lead one to expect, if the relief of the district had had a uniform history, that the ravines among the adjacent mountains would be narrow V-shaped valleys. But this is not the case. Among the hills the valleys are comparatively broad, and they are so continuous, both along and across the range, as to divide it, even within the limited area of our observation, into many separate groups of heights. The aspect of the range indeed reminds one of the mature features of Shan-tung, or suggests a mountain mass like that just north of T'ang-hién, the only difference being that the one is exposed to its base and the other is largely buried.

Since the canyon of the Hang-ho is young and the valleys of the mountain district are relatively mature, we are shut out from any explanation which involves the assumption that the river is older. For example, we may not assume that the Hang-ho had its present course on a peneplain above the mountain summits, and has sunk its canyon after the fashion of an antecedent river, during the upwarp of the mountain range. Were that the case the valleys among the mountains would exhibit the features of youth which characterize the Hang-ho. Nor does it seem probable that the Hang-ho, as a tributary of the T'ang-ho at Si-ta-yang, has grown by headwater erosion from the proportions of a small gully not more than a couple of miles long, across the range, and so diverted whatever drainage formerly existed in the Ning-shan basin. The differences of elevation on the two sides of the range, and the watershed which we might assign to the incipient Hang-ho, are both too limited to afford foundation for such a hypothesis.

To understand the course of the Hang-ho above Si-ta-yang, let us consider the course of the rivers below that point, and the peculiar features of the buried topography. It is evident that, beneath the plain, there is a very mature topographic surface which emerges from under the Huang-t'u formation along the southeastern side of the Ning-shan district. The mountains bounding that district are of that mature stage of development. Before the accumulation of the Huang-t'u formation they had reached a degree of valley erosion resulting in the wide expansion of the valley plains and the isolation of the hills. With the accumulation of the Huang-t'u formation, the hills were to a greater or less extent buried, and the streams, in whatever direction they flowed, acquired aggraded channels on a surface above the bed-rock. In describing the region, reference was made to the valley plains between T'ang-hién and Nan-t'ang-meï, and in the Ning-shan basin, which represent the courses of

streams that flowed southwestward. These ancient streams were instrumental in the development of the mature topography. It is probable that they maintained their courses during the accumulation of the Huang-t'u formation, and aided in distributing it. If we suppose that the accumulation of the Huang-t'u went on until the old rock divides—which were, in consequence of their age, very low—were buried, we should then have a region of more or less isolated hills, such as we now find between T'ang-hién and Si-ta-yang, but extending further northwestward, at least into the Ning-shan basin. Were this surface tilted downward toward the southeast, the growth of gullies in the Huang-t'u formation would take place in a northwest direction, across the lines of ancient drainage, yet within the transverse valleys of the old topography. The old drainage would be diverted, and such a stream as the Hang-ho would be the result. If, in consequence of the tilt, some part of the bed-rock surface were sufficiently raised, it would be denuded of the Huang-t'u formation and the old surface more or less clearly exposed. The valley of the Hang-ho would be in part characterized by features of the mature valleys, within which it had developed, and in part by youthful features carved from the ridges, upon which it had been superimposed. On the other hand, that portion of the old surface which, in consequence of tilt, sunk lower would become the area of aggradation and deeper burial, such as we recognize as the outer margin of the foothills.

If the preceding interpretation be correct, we find between T'ang-hién and Ning-shan evidences of the following stages of physiographic development:

n: A stage in which the relief of the region had reached advanced maturity with the development of wide valleys and more or less isolated hills and groups of hills. The streams of this stage flowed southwestward, and two of them are recognized in the valleys northeast and southwest of Ning-shan.

$n + 1$: The mature topography of the stage n was buried beneath the Huang-t'u formation to a depth sufficient to cover the rock divide between Si-ta-yang and Ning-shan.

$n + 2$: The surface was tilted southeastward, with the result that the rivers of the stage $n + 1$ were cut into sections in consequence of the growth of streams on the sloping surface of the Huang-t'u. In some instances these sections appear to have retained enough of their headwaters to continue as parts of the present drainage, constituting a northwest-southeast element of the streams. Such is the T'ang-ho between Nan-t'ang-meï and Si-ta-yang. In other instances diversion has been at such intervals as to isolate a part of the old valley and leave it practically

without drainage, as is the case with the valley northeast of Si-ta-yang, or with the Ning-shan valley between the forks of the Hang-ho and the Sha-ho. The relations of elevation and depression in consequence of tilt during the stage $n + 2$ have been such as to cause the removal of the Huang-t'u formation over a part of the area of the mountain range between Si-ta-yang and Ning-shan, and to lead to the deeper burial of the region southeast of Si-ta-yang.

Referring now to the headwaters of the Hang-ho, we again have an example of stream development transverse to the structure, and one of rather striking character, since the two branches of the Hang-ho head in the district of bad lands, on soft gneiss, and flow directly into a range of limestone hills, 1,500 feet, 450 meters, higher than their channels. It is possible to extend the explanation, which seems adequate for the lower course of the Hang-ho, to these headwater streams, and such an explanation may suffice. These streams and the parallel course of the Sha-ho may, however, have an earlier origin, determined by the normal fault. In consequence of that fault, the area of the basin on the downthrown side sank lower than the area of gneiss on the upthrown side, and consequent streams originating on the fault-scarp must have developed with courses at right angles to the fault and with a valley from northwest to southeast. Such streams may have been the ancestors of the Hang-ho and Sha-ho. In that case they probably joined the river which occupied the Ning-shan basin and flowed southwestward with it, their diversion to the present course toward the southeast being a matter of later development, as has already been discussed.

*The Sha-ho below Fóu-p'ing-hién.**—The valley of the Sha-ho below Fóu-p'ing-hién presents no striking physiographic features. It is aggraded with sand and gravel to a width of from half a mile to a mile, and bounded by steep rock bluffs. These latter sometimes rise 100 to 200 feet boldly from the river bank, and occasionally form an obstacle to traffic, as in the case at a point 2 miles, 3 kilometers, below Wang-k'uai-chön, where the path is forced over a dangerously steep ridge by the convergence of the river against the base of a cliff. The elevation of the channel above sea is 500 feet, 150 meters, near Wang-k'uai-chön and 800 feet, 240 meters, 24 miles, 38 kilometers, upstream, near Fóu-p'ing-hién. At the summits of the neighboring hills, the outlook is over the area of bad lands, which at once suggests a wide valley level developed to old age, with complete adjustment to the distribution of hard and soft rocks. This may be regarded as the valley of a large stream which occupied the belt between the Ning-shan basin and Fóu-p'ing-hién, and,

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*Atlas sheet E I.

like other streams of the earlier stage, flowed southwestward; but as we have not traced this valley toward the northeast or southwest, we have no means of knowing its extent. Whatever its character may have been, the stream or streams which occupied it were diverted by such as originated on the Ning-shan fault-scarp and have now become the headwaters of the Hang-ho or tributaries of the Sha-ho.

The Sha-ho above Fóu-p'ing-hien.—I have already described in some detail the peculiar features of the canyon of the Sha-ho above Fóu-p'ing-hién, and the relations of its northwestern and southwestern forks. Taken in connection with the direct but abandoned channel between Li-yüan-p'u and Fóu-p'ing-hién, they present an interesting case of diversion. To abbreviate the discussion, we may make use of the diagram in Fig. 58.

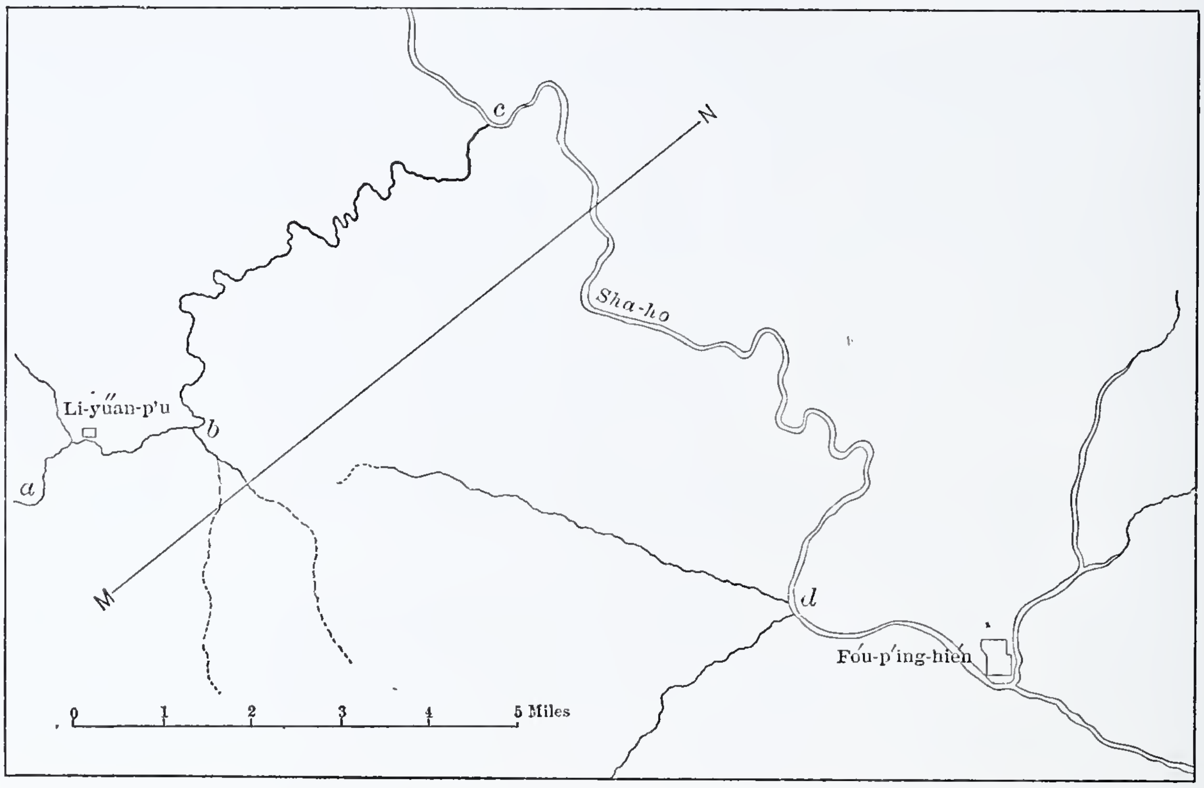

FIG. 58.—Map showing the course of the Sha-ho between Li-yüan-p'u and Fóu-p'ing-hién, Chï-li; *abcd* being the present course and *abd* the former course of the western branch of the stream.

Let *ab* represent the relatively wide aggraded valley about Li-yüan-p'u, and *bd* its abandoned section between Li-yüan-p'u and the junction of the Sha-ho. Let *cd* represent the canyon of the main fork of the Sha-ho, and *bc* the present course of the diverted southwest fork. Let the rock masses in which the channels are cut be essentially homogeneous, they being banded gneisses of flattish attitude. Then the problem is to discover conditions under which the stream *abd* may be diverted from its direct course as a tributary of the larger stream *cd*, and the canyons which now characterize the established channels developed.

The evidence in support of the assumption that the original course of the streams was by the valley *abd*, and not by the valley *abc*, has been given in describing the features of the region. It is found in the fact that the section *bd* is an old aggraded valley, in which there is a divide established on the Huang-t'u formation, and the channel *bc* is a characteristically youthful canyon.

There is nothing in the conditions of rock structure to help us toward a solution, but if we draw a line MN, from southwest to northeast, between *b* and *d*, we find that the canyon of the main river and a rather sharply cut gorge in the lower abandoned valley lie to the southeast of it, whereas a more open valley on the upper northwest fork and the aggraded valley of Li-yüan-p'u lie northwest of it. These relations of narrow, incised channels on the one side and widened, aggraded valleys on the other are intelligible if we assume that there was a local upwarp, of which the line MN was the axis. In consequence of such an upwarp, both of the streams *abd* and *cd* would be retarded on its northwestern side and accelerated on the southeastern slope. If they were strong enough to maintain their courses as antecedent streams, both would be characterized by canyons in the respective stretches *bd* and *cd*. If, however, either of them was unable to maintain its course while the other succeeded in doing so, the weaker would be reached by a tributary of the stronger and diverted to a course along the northwestern side of the upwarp. This is what appears to have taken place. In consequence of an upwarp, giving rise to the notable heights which form conspicuous outliers of the main range northwest of Fóu-p'ing-hién, the main Sha-ho, *cd*, though retarded in its upper reaches, cut the canyon which characterizes it, and maintained its course. The southwestern fork, *abd*, on the other hand, failed to accomplish the task of canyon cutting with sufficient rapidity, and was so checked that it deposited not only gravel but also loess in its upper valley. While in this condition, whether absolutely ponded or merely rendered sluggish, it was reached by the southwestern branch which joined the main river at *c*, and the diverted waters developed the latest of the several channels, the canyon of the section *bc*.

This explanation involves the assumption of the development of a relatively narrow upwarp having a northeast-southwest trend, and if the assumption applied only to this individual case it might be regarded as having slight foundation, but we shall see in the further discussion of the features of the mountains that there has been pronounced warping along axial lines having the same general trend, and the upwarp, as a feature common to the region, may be regarded as a reasonably probable local detail. The test of the hypothesis would lie in a closer study of

the contours of the valleys, which, if the explanation be correct, should exhibit the older valley features warped above the canyon on the section *cd* and above the sharply cut portion of the abandoned valley *bd;* and these same old valley features should sink to the level of the upper valleys northwest of the point *c* on the main river, and west of the point *b* on the southwest fork.

The upper valley of the Sha-ho above the curious point of diversion—that is, from Li-yüan-p'u to the divide—is characterized by the features of a stream which has grown through the development of its headwater gullies on a steep slope. Its drainage area is narrowly limited by a mountain rim, which bends around it everywhere, at a nearly equal distance from the main channel. The tributaries are all of approximately the same length, and spread like the twigs at the end of a branch of a deciduous tree. They gash the mountain slopes into hundreds of ravines, and are growing vigorously at their extremities as they energetically sink their deep channels. The valley is a beautiful example of the headwaters of an autogenous stream, which, developing upon a steep slope, is rapidly extending the area of its watershed.

If we look for evidences of stages of development in the history of this upper valley, they are meager, because the growth has been rapid and without prolonged interruptions, but they are not altogether wanting. The latest incident is expressed in the relatively wide and flat valley floor above Li-yüan-p'u, which has already been interpreted as an effect of local warping. Evidence of similar widening, which probably was of greater extent and longer duration, is found in the flats on the mountain spurs, representing an old valley floor about 1,800 feet, 530 meters, above the present channel, above Lung-ts'üan-kuan. The present elevation of these spurs is not far from 4,400 feet, 1,340 meters; that is, but little below the crest of the pass, 4,800 feet, 1,350 meters, and practically the same as the altitude of the valley of the Ts'ing-shui-ho, just across the range. It is probable that this old valley stage corresponds with that which is marked *b* in the sketch, Plate XXX, representing the view looking northwest from the divide above Lung-ts'üan-kuan. If so, the features now lie several hundred feet lower on the eastern side of the divide.

The characteristics of the upper Sha-ho are, without exception, those of a stream developing on a steep slope. The process of development is still progressing, and the river has immediately before it the diversion of the Ts'ing-shui-ho and upper T'ai-shan-ho, which will probably take place through the lowest pass, that above Lung-ts'üan-kuan, and result in an inversion of the Ts'ing-shui-ho above Shï-tsui.

The condition which has given the Sha-ho the opportunity for vigorous growth is the elevation of the mountain mass of northern Shan-si above the district of Fóu-p'ing-hién, in which the Sha-ho was already developed. We have, in the ragged spurs of the southeastern slope from the divide above Lung-ts'üan-kuan to Fóu-p'ing-hién, the scarcely recognizable remnants of the older surface, that has been tilted and thoroughly cut to pieces by the accelerated and rapidly growing consequent streams.

The T'ai-shan-ho, Hu-t'o-ho, and tributaries.—The T'ai-shan-ho has a general southwesterly course. It rises in Pre-Cambrian rocks of the T'ai-shan complex and Wu-t'ai schists, and flows from them into a synclinorium in the Paleozoics. Disregarding the minor details of its windings, it is adjusted to the structure of the formations and occupies a synclinal valley, down which it flows in the direction of the pitch. It seems probable that it is a very ancient stream, which originated in a syncline on the Shan-si coal-measures at the time of the Post-Paleozoic folding, and has survived the vicissitudes of erosion and uplift. Its position is now very vulnerable on account of its elevation above the low valleys of eastward flowing streams like the Sha-ho.

The T'ai-shan-ho is indifferent to the relations of hard and soft rocks. The schists upon which it takes its rise yield far more readily than the limestones in which it has its lower course, but it leaves the wider valley for the narrower canyon without any evidence of adjustment to the resistance of the rocks. Its principal tributaries do likewise; heading in the southwestern prong of the Wu-t'ai range, they flow across the lowlands of the loess basins, which are cut out of soft Pre-Cambrian slates, and enter deep canyons in the Paleozoic limestone in order to join the T'ai-shan-ho. This is true not only of the smaller streams, but even of the Hu-t'o-ho, the largest of the region, which, having its sources far to the north, flows southwesterly into the great Hin-chóu basin, winds to the northeast through a narrow pass into the Tung-yü basin, and then plunges into the canyon to join the T'ai-shan-ho in a general southeasterly course.

We may describe the valley of the Hu-t'o-ho above Hin-k'ou as one which is adjusted both to the structure and to the softer rocks. It lies approximately parallel to the strike of the schistosity and folding in the Wu-t'ai range, and is bounded on the west by escarpments of the Sinian limestones; that is, it has developed in a zone of weak schists below the base of the Paleozoic. It, also, is probably an ancient river. Beyond the Hin-chóu basin the natural course of the Hu-t'o-ho is through the Shï-ling to the basin of T'ai-yüan-fu, where it would join the Fön-ho and pursue its way down the graben of central Shan-si. We are not able to prove, by the occurrence of river gravels or other direct evidence, that

the Hu-t'o-ho did once follow this course to the Fön-ho, but the wide valley which leads across the Shï-ling and down past Huang-t'u-chai is a feature which is clearly stamped with the characters of a much larger stream than any that now occupies it, either north or south of the pass. The elevation of the pass is of later date, not only than the erosion of the wide, mature valley, but also than the deposition of the Huang-t'u within that valley, for, in the basin of Huang-t'u-chai, the formation of that name is evenly stratified, like a deposit laid down in quiet water, up to an elevation of 3,300 feet, 1,050 meters; that is, 600 feet, 180 meters, above T'ai-yüan-fu. It is not possible that any water surface could have covered the plain at this level. Furthermore, the moderate activities of the intermittent streams, which now flow northward and southward from the Shï-ling, are sufficient to deeply trench the Huang-t'u formation. The growth of autogenous canyons within the formation is energetic; and even the wind is engaged in scouring away, rather than in depositing, the prevailing loess. There is no agency of wind or water which seems capable of spreading the Huang-t'u over the pass and depositing it as a finely stratified mass in the basin of Huang-t'u-chai, at its present altitude. Hence it is inferred that, through upwarping, the Shï-ling has developed the character of a divide, which it now possesses.

Though based on independent evidence, the inferred upwarp is in agreement with the great elevation of the Ki-chóu-shan. The fault-scarp, which marks that range, ends northeast of the Shï-ling, and the warped surface of the mountain face extends southwest, not only to, but beyond, the pass.

We thus have good reason to regard the Shï-ling as an elevated river valley, and, by a reasonable interpretation of relations, as the former river valley of the Hu-t'o-ho.

The diversion of the Hu-t'o-ho from the Hin-chóu basin eastward was a direct consequence of the closing of the Shï-ling outlet. Whether a lake formed in the basin and overflowed at the lowest col, or a tributary of the river at Tung-yü captured the sluggish Hu-t'o-ho, we do not know; but either process is likely to have occurred under the conditions, and either suffices to explain the diversion.

History of the Huang-ho.—Of China's great rivers the Huang-ho is the second, and its history involves the interpretation of the events of at least the whole of the Pleistocene period and probably some part of the Tertiary. I do not propose to offer, on the basis of our slight observations, an elucidation of the story of the river, which has probably had a complex development, but I wish, in connection with this chapter on the development of streams, to point out some of the characteristics that

distinguish it from ordinary rivers, and especially from other rivers of equal magnitude.

The middle Huang-ho has no considerable valley. If we attempt to follow it from its delta on the great plain of eastern China, we have, indeed, a channel which marks a continuous river, but we have not a valley of erosion which we may attribute to the stream. As we saw it at the Tung-kuan, and as it is described in its course from that point eastward, it is a stream occupying a depression produced by normal faulting. It has taken possession of a channel, but has not made one. In its long course from north to south, above the great elbow between the provinces of Shan-si and Shen-si, it flows much of the way in a canyon, and where not bounded by cliffs of rock it is shut in by walls of loess. Some portions of its channel appear to be antecedent to upwarps in the surface, and we are thus thrown back to an earlier date than that of the warping for the beginning of the river's course. But it appears from descriptions given of the valley in works of travel or by the natives, that nowhere in its lower section is the river accompanied by that wide channel of an older valley which we would expect if it had long flowed in its course across the surface. On making inquiries at T'ai-yüan-fu and Fön-chóu-fu, regarding the possibility of a journey along the river's banks, we were told that such a trip would hardly be possible. The steep bluffs against which the river impinges, and the many gullies extending down to the stream, would make it difficult for a pack train to pass, while on the other hand, the many shallows and rapids in the current make it dangerous for boats. In seasons of high water the river is navigated by boats, which carry coal downstream to Si-an-fu, but no boat is ever taken upstream. Thus it seems that the only practicable opportunity to make a reconnaissance of the river is the rather unsatisfactory one of running it in flood time.

These characteristics of the river valley point to unusual youth, and apparently indicate an absence of an earlier history. Without being able to speak from full observation, we are thus led to infer that the Huang-ho is a youthful stream, and we may propose as a working hypothesis the following theory of its development. Let it be assumed that the Huang-t'u formation was spread upon a relatively mature surface of erosion, and that its accumulation formed an extensive plain of aggradation, in which the old topography was, to a considerable extent, buried. Let it be assumed, furthermore, that this surface was tilted, so that the northwestern portion lay higher and the southeastern portion lower; that is, that it was depressed toward the downthrow of the great normal fault-blocks of Shan-si and Shen-si. Prior to the tilting there may have

existed a large river, the initial Huang-ho, which meandered in the graded valley on the Huang-t'u; or, as a result of tilting, a large stream may have developed by rapid headwater erosion and repeated capture, taking a consequent course on the tilted surface. The latter, in view of the present course of the river, from the highlands of Mongolia toward the lowest point of the downthrow of the great fault-system, seems to be the more probable origin of the Huang-ho. The stream, being once established, has maintained its way in spite of later warpings of the surface, and has adjusted itself in its lower course to the single exit provided by the great east and west fault of the Ta-hua-shan.

PHYSIOGRAPHIC STAGES.

In the former of the two preceding sections on the physiography of northwestern China, a descriptive statement of observations of physiographic facts has been given. The second has reference to the growth of the rivers, which among physiographic facts are commonly the oldest and always the most expressive features of the country. In describing what we saw, frequent reference has been made to the youth or maturity of the phases of topography and the great differences in this respect noted among closely adjacent features of the region. On the summits of the Wu-t'ai-shan, at altitudes of 8,000 to 10,000 feet, 2,400 to 3,000 meters, above sea, there is an ancient topographic surface which has the aspect of a peneplain. In that same mountain mass we recognized in the high ridges below the broad old summits a surface of mature erosion, and this phase we have found to be widely distributed. We saw it among the foothills of the mountains along the western margin of the Great Plain in the vicinity of T'ang-hién; we saw it in the loess basins about Wu-t'ai-hién; and it was observed in the valley of the Fön-ho, between T'ai-yüan-fu and P'ing-yang-fu. This mature surface is generally more or less covered by the Huang-t'u formation, except in the Wu-t'ai-shan, where, being deeply dissected, it is represented only by rocky ridges, from which any deposit that may have rested upon them has been eroded. The epoch during which the Huang-t'u formation was spread over the surface succeeded that of mature erosion and is distinct from it. The Huang-t'u formation being a deposit resulting from unusual conditions of aggradation, the corresponding epoch is distinguished by that fact from those epochs during which denudation was the prevailing activity of the region. Still another, a fourth, phase of physiographic sculpture was seen along our route, and it is one which offers the most striking features in the scenery of the region. It is the canyon aspect of much of the mountainous area. All of the streams whose valleys traverse districts outside of the

areas covered by the Huang-t'u are, in certain stretches, sunk in deep canyons, which are confined by steep slopes in the Pre-Cambrian rocks and in the Paleozoic limestones are walled by bold cliffs. These characteristics are features of youth, and the canyons compare in appearance and depth with the great normal fault-scarps of the Ki-chóu-shan and the Ho-shan.

The four groups of features thus recognized occur widely distributed throughout northwestern Chï-li and northern and central Shan-si. In our journey we traversed them for a distance of more than 500 miles, 800 kilometers. They are, therefore, not accidents of a local character, but wide-spread physiographic types, which are as significant records of the later history of southeastern Asia as the geologic formations are of the Paleozoic and Pre-Cambrian history. The physiographic stages may be defined, named, and ordered in sequence, much as we would arrange and interpret the members of a stratigraphic succession. In so doing we shall find that the four types are more or less widely distributed and lie in various relations to one another, both in horizontal extent and in altitude. We shall be obliged to recognize that these relations can not have developed as they now exist without interaction of the processes of mountain growth and mountain sculpture, and that not only changes of elevation, but also changes of climate, have been involved in the development of the history.

In what follows, the four stages of physiographic development are designated: Peï-t'ai, the oldest, T'ang-hién, Hin-chóu, and Fön-ho. They are believed to cover much of the Tertiary and the Quaternary.

PEÏ-T'AI STAGE.

In the preceding pages reference has repeatedly been made to the rounded forms of the high summits of the Wu-t'ai-shan, of which Peï-t'ai is not only one of the highest but also the broadest. Its aspects are represented in the view (Plates XXXII and XXXIII) and in the panorama of the Wu-t'ai-shan on atlas sheet E I. We take this broad flat form to represent a stage of erosion of advanced old age, the nearest approximation to a peneplain which we found in the course of our journey. The surface lies above all other features, and consequently is older than they. This oldest and most aged form, which is represented in the rounded summits of the Wu-t'ai-shan, we name, from the conspicuous and characteristic dome in which it is best exemplified, the Peï-t'ai surface. Considered as a phase of topographic development, which was reached through prolonged erosion, we may designate it the Peï-t'ai stage; and the corresponding epoch may be called the Peï-t'ai epoch.

The Peï-t'ai surface is capable of two interpretations, between which it is difficult to discriminate. It may either have been a well-developed peneplain, or an aged surface which was still relieved by monadnocks rising above broad and shallow valleys. If it ever was a nearly flat peneplain it was later slightly elevated and suffered moderate erosion resulting in the development of low, rounded residuals, of which Peï-t'ai is the type. If it never was well planed, Peï-t'ai and other similar summits are monadnocks reduced from higher elevations. The distinction is one which belongs to a finer classification of physiographic history and can not be made without more adequate criteria than we now have. It is not important, for the region had in either case undergone prolonged erosion and had been reduced to the aspect of advanced old age.

The aged surface of the Wu-t'ai-shan is covered by residual soil, a mantle of decayed rock or saplite. The material is a reddish sandy clay, which consists of the products of decomposition of the schists, in which there yet remain many angular joint-blocks of the obdurate rocks. The superficial aspect of the mantle is seen in Fig. A, Plate XXXII, where it covers a wind-swept pass at 8,000 feet, 2,400 meters, above sea; and its internal constitution may be inferred from the gullies and coarse deposits of rock fragments in Fig. B, Plate XXXIII. We regard this mantle of saplite as the lowest part of a deep zone of decayed rock, which accumulated during the Peï-t'ai stage, and which has been greatly denuded during subsequent stages. In most districts of eastern and central Asia it has been completely removed from its original areas, and has furnished much of the materials of the Huang-t'u formation; but on the Wu-t'ai-shan it remains within the surviving area of the Peï-t'ai form.

Recognition of the Peï-t'ai stage and of the profound erosion which was accomplished before its close is important to an understanding of the relations of the present topography to the structure of the mountains. It follows from that recognition that whatever heights had existed before or during the beginning of the Peï-t'ai had vanished by its end, and therefore no mountains due to folding then survived.

T'ANG-HIÉN STAGE.

The T'ang-hién stage corresponds with that phase of topographic development which is represented by the mature surface carved on the Pre-Cambrian schists and the Paleozoic strata. It is recognized by its topographic forms of which the most characteristic are the wide valleys associated with numerous and more or less extensive monadnocks. It is typically developed in the northern Loess Basins and near T'ang-hién, Chï-li, in the hills along the western margin of the Great Plain. Its name is taken from the latter locality.

The relief of the T'ang-hién stage—that is, the height of the hills above the adjacent valleys—varies from 300 feet, 90 meters, to possibly 1,000 feet, 300 meters, with a general average of 500 feet, 150 meters, or less. The forms of the surface are usually rounded and smoothly modulated. In the distribution and extent of the valleys and in the insignificant altitude of the divides the topographic aspects closely resemble the features of Shan-tung. The wide valleys are the result of erosion, their continuity across divides is the result of head water competition, and the isolation of the numerous low hills has followed from the extensive development of every line of drainage.

Areas having the characteristics of the T'ang-hién stage were recognized throughout our route across Chï-li and Shan-si. In the neighborhood of T'ang-hién, where the surface rises from beneath the great level plain of eastern China, it appears first in isolated island-like hills, and may be recognized more extensively in the flat valley plain and the adjacent hills northeast of Si-ta-yang, and in the Ning-shan basin. The elevation of the valleys of the T'ang-hién stage is here about 400 feet, 120 meters, above sea, but as the surface sinks beneath the alluvium of the plain and the hills greatly diminish and are buried eastward, it is probable that it soon passes below sea-level. It is possible that features of the bad lands along the Sha-ho east of Fóu-p'ing-hién to some extent represent it, but no definite recognition of any specific form is possible in that deeply denuded region. The characteristic forms are also wanting on the upper Sha-ho. It was not until we reached the divide above Lung-ts'üan-kuan that we were again able to see, in the profiles of the Wu-t'ai-shan, the outlines of the surviving features of mature aspect which might be assigned to the T'ang-hién epoch. These features have been referred to in previous descriptions and are illustrated in Plate XXX, where they are designated by the letter "*b*."

After recognizing the T'ang-hién stage in the Wu-t'ai-shan, we lost sight of its representative features in descending to the Loess Basins, and did not again find them until we studied the region about Wu-t'ai-hién. In the mountains of Paleozoic limestone southeast of Wu-t'ai-hién, the broad uplands clearly present the surface of mature erosion, which we assign to the T'ang-hién, and this mature surface was traced from the summits of the limestone mountains northwestward into the valley at Wu-t'ai-hién, and was recognized as prevailing in the hills all about tht Loess Basins. It there has the characteristics which it exhibits near T'ang-hién, the hills being sculptured from rocks of similar weakness and being to a great extent buried in the prevailing Huang-t'u formation.

The aspects of the Shï-ling pass and of the old river valley in the vicinity of Huang-t'u-chai are typical of the T'ang-hién stage. The moun-

tains on the east, which are the southern extension of the Ki-chóu-shan, and the plateau on the west, which is of the Ordovician limestones, appear also to be crowned by surfaces of typical mature character, but at a much higher level. It would follow that, in recognizing the identity of features of the T'ang-hién stage in the basin of Huang-t'u-chai and in the adjacent mountains, we must accept the evidence of their former continuity and admit that they have since been warped to different levels.

In the valley of the Fön-ho, from the southern margin of the basin of T'ai-yüan-fu to a point south of P'ing-yang-fu, features of the T'ang-hién stage were recognized in mature topographic forms sculptured upon the sandstones and shales of the Shan-si series and covered by Huang-t'u; but the soft rocks are deeply cut by narrow ravines, and the older features are not readily recognized in detail.

It is probable that the south slope of the Föng-huang-shan is also characterized by features of the T'ang-hién stage. It has a flat, slightly hilly surface, which is now tilted, but was formerly much more nearly level. In consequence of the tilting it is being dissected, yet the process has not proceeded far and the aspects of its features justify us in calling them T'ang-hién.

In the several districts in which we find features that we assign to the T'ang-hién stage, there is but one characteristic upon which to base a correlation. It is that of physiographic maturity. Wide valleys, low relief, and the isolation of monadnocks as individuals or in groups, are the topographic characteristics common to all the areas placed in this class. In other respects there are marked differences between the districts. Thus with reference to altitude above sea: southeast of T'ang-hién the surface probably extends below sea-level, and in the vicinity of that city has an elevation of only 300 to 400 feet, 90 to 120 meters. In the Wu-t'ai-shan the altitude of the ridges which are taken as representing the stage is from 5,000 to 5,500 feet, 1,500 to 1,650 meters. In the Loess Basins about Wu-t'ai-hién the elevation is 4,000 to 4,500, 1,200 to 1,350 meters, and in the limestone mountains southeast of Wu-t'ai-hién and in the Ki-chóu-shan it is again higher, namely, from 5,000 to 6,000 feet, 1,500 to 1,800 meters. In the valley of the Fön-ho the T'ang-hién surface, as there recognized, rises from 2,700 feet, 825 meters, in the vicinity of T'ai-yüan-fu to nearly 4,000 feet, 1,200 meters, between Ling-shï-hién and Ho-chóu, but descends again to about 2,600 feet, 800 meters, near P'ing-yang-fu. Thus it is apparent that altitude above sea is not a criterion by which we may distinguish features of the T'ang-hién stage. The total range in elevation within the area of our observation being from below sea to 6,000 feet, 1,800 meters, above sea, greater range is quite possible.

Another fact which makes difficult the recognition of the T'ang-hién surface is the lack of constant relations to features of earlier or later stages. It commonly happens in a district, where the development of successive physiographic stages has been somewhat uniform, that one may find the features of different epochs represented in regular order in the mountain slopes as one ascends from canyon to summit. Under such conditions the youthful canyon and older valley floor in which the canyon is cut may be recognized. There may be other stages of older valley floors, and perhaps a higher level which represents the peneplain, the oldest surviving topographic feature. Where a complete sequence of features is thus preserved, the recognition of any one is aided by its relation to the others. The case is similar to that in the study of strata, where we sometimes identify a geologic formation by its relation to clearly defined strata above or below, even though its own characteristics are somewhat obscure. But in reference to features of the T'ang-hién stage we are unable to apply this method of identification, since the development of the topography of the region has been unlike in different districts. Thus in the area in which the mature features of the T'ang-hién stage are now elevated, as in the Wu-t'ai-shan and Ki-chóu-shan, they are seen to be dissected by younger canyons. But in the vicinity of T'ang-hién and in the Loess Basins, the surface which we assign to the T'ang-hién stage is not dissected. It is the latest surface of erosion. There are indeed some exceptions to this general statement; for instance, the valley of the Hang-ho above Si-ta-yang is characterized by some youthful aspects, which have been attributed in the preceding description to the fact that the stream was superimposed upon the low divides of the underlying mature topography; but as a whole it is true that, in the topography of the southeast foothills or of the Loess Basins, there are no widely developed features younger than those of the T'ang-hién epoch. In these districts, on the contrary, instead of being dissected, the features of the T'ang-hién stage are covered by the Huang-t'u formation. The areas in which they are thus buried are distinguished as areas of aggradation from those of degradation, in which they are cut by the canyons of a later epoch.

Though neither altitude above sea nor position in sequence of topographic forms can be relied upon as criteria by which to identify the T'ang-hién stage, its widely separated occurrences are correlated with confidence on the basis of a common physiographic phase, that of advanced maturity. Maturity is a phase reached only after erosion has been active during a considerable length of time. When the features of advanced maturity are stamped upon an extensive region, the epoch of degradation must be recognized as one of notable duration, even geologically speaking. Hence the correlation of features as belonging to the T'ang-hién stage is not a

narrow one within exact limits. It is a broad one, sufficing to place in true relative sequence a stage of development reached by different areas in different degrees within longer or shorter time, but a stage reached by all essentially contemporaneously within the limits we can now set for the beginning and end of the epoch.

The T'ang-hién epoch began with an elevation, which resulted in general dissection of the still older and more aged features of the Peï-t'ai surface. It ended with the initiation of those changes of level and climate which occasioned the deposition of the Huang-t'u formation; that is, when the degradation in the region under discussion gave place to aggradation. And with the close of the T'ang-hién stage began the Hin-chóu stage.

HIN-CHÓU STAGE.

The Hin-chóu stage differs from the two preceding ones in being an epoch of aggradation within the provinces of Chï-li and Shan-si. The principal fact was the accumulation of the earlier deposits of the Huang-t'u formation. We must distinguish the stage of earlier deposits, at least theoretically, in classification, because the Huang-t'u has been forming since the beginning of the Hin-chóu epoch and is forming now. Therefore the Huang-t'u period covers all the time since that beginning, but the Hin-chóu epoch does not. It was closed by warping, to which the major orographic features of northern China are due, and that warping initiated the latest epoch, which we call the Fön-ho. The Huang-t'u period is, therefore, equal to and coincident in time with the Hin-chóu and Fön-ho epochs together.

The accumulation of the Huang-t'u formation can be discussed only as a phase of the loess problem of China, a problem which has been involved in much misconception because the physiographic conditions of the Hin-chóu stage were not understood, and because the characteristics of the Huang-t'u formation present difficult questions for solution. If the interpretation of the physiographic history, which leads to the recognition of the Hin-chóu stage of mature topography, be correct, we have gained a point of view from which to discuss the unusual character of the Huang-t'u. Let us glance at the earlier conceptions of its development.

Earlier theories of Chinese loess.—Pumpelly described the loess or Huang-t'u formation as a lake or terrace deposit.* He attributed the formations of the lake basins to the dislocation of the plateau of North China, and traced a former connection between the valleys in which he observed the loess and the present course of the Yellow river.

* Smithsonian Contributions to Knowledge, vol. xv, pp. 39–45.

Pumpelly wrote:

That this deposit was formed in fresh water is shown by the presence of the shells found in the terrace of the Té-Hai. The uniform character of the loam in the different basins, and in all parts of the same basin, its great extent, and the fineness of the material of which it consists, are conditions which prove that it is not of local origin, or derived from the detritus of the neighboring shores, but that it was brought into the lakes by one or more large rivers, which must have drained an area of great extent. Now, throughout the region in question, the only rivers are those of the Yang-ho and Sankang-ho basin, and independently of the fact that these streams drain a very small area, the valley systems of these were almost entirely occupied by the lakes. Indeed, the only direction from which a river of importance could have come was from the west, in which case it could only have been the Huang-ho (Yellow river). Let us examine into the possibility of the existence of a communication of a valley of the Yellow river and the lake basins.

The further discussion given by Pumpelly is an attempt to trace the possible changes in the river course, an attempt which, in the meager knowledge then available of the geography of China and of the physiographic processes by which streams may be diverted, is necessarily little more than suggestive, but which, nevertheless, indicates a bold grasp of some of the elements of the loess problem. Our own interpretation agrees with that of Pumpelly, in that we consider the formation under discussion to be a valley deposit, but differs from his in assigning to rivers the principal part in its extensive distribution.

Von Richthofen, having observed the distribution of the loess more widely than Pumpelly was able to do, showed that the hypothesis of a lake formation was untenable on the ground that the loess occurs at such altitudes in the Wu-t'ai-shan and elsewhere in Shan-si, that no barrier could be conceived which might retain a body of water capable of accumulating the deposit. Pumpelly accepted this view.*

Von Richthofen held that the mountains of China had gained the altitude which they now have before the loess was laid down. He says:

We reach, in fact, the surprising result that the loess, in its vertical distribution, is independent of altitude above sea, and, with the exception of individual dividing mountain ranges, is found everywhere where a foundation for it occurs—provided that it has not been eroded or covered by alluvium. Now it can be proved that since the time of its formation there have been only slight relative changes of level in North China. In general at the time of its development, the surface forms of the region were nearly the same as now; the general elevation was, however, higher than at present, and the coast line was shoved farther out in the sea. The loess differs, therefore, from all other formations of like magnitude, in the remarkable fact that it was laid down in those relative altitudes

* Relations of Secular Rock Disintegration to Loess, Glacial Drift, and Rock Basins. American Journal Science and Arts, vol. XVII, February, 1879.

in which we now find it. Its accumulation occurred contemporaneously in the deep canyon of the Huang-ho and on the heights of the Wu-t'ai-shan. This preliminary consideration leads directly to the conclusion that the loess owes its development to processes of formation which are not commonly assumed in reference to other deposits of like composition and magnitude.*

In quoting the preceding from the volume published in 1877, it is but just to von Richthofen to state that, as his studies in orogeny progressed, he modified his views regarding the age of the mountains of northern China, and in March, 1905, when the results of our observations were laid before him, he met the facts of physiographic history with appreciation of their significance.

The assumption that the Huang-t'u was laid down on a surface having the present mountainous relief, we now hold to be mistaken. We recognize that the surface beneath the Huang-t'u formation is one of mature topographic aspect, which could have developed only in a relatively low altitude with reference to the sea, and we are able to describe features of the mountains which must be assigned to a later epoch than that of the earliest Huang-t'u deposit.

The conception that the loess has been laid down upon a region having the present strong relief of the mountains of northern China led von Richthofen to an extreme inference regarding the work of the wind as the principal agent involved in its distribution. The extraordinary situations in which the Huang-t'u is now found, on the slopes and even on the summits of hills, where it occurs sometimes in a thick and isolated mass, places the formation outside of any class of alluvial deposits, and its occurrences are sometimes such as to occasion difficulty even in attributing them to wind action. Nevertheless, von Richthofen correctly recognized the importance of the wind as a dominant agent in the production of the loess; that is, in the sorting and local distribution of the fine dust of which the loess proper consists. By sound inference from the conditions now existing in the steppes of central Asia, he rightly ascribed the unusual

*China, vol. 1, p. 64. "Es ergibt sich in der That das überraschende Resultat, dass der Löss in seiner verticalen Verbreitung von der Meereshöhe unabhängig ist und, mit Ausnahme einzelner trennender Gebirgskämme, überall angetroffen wird, wo eine Grundlage für ihn vorhanden ist—vorausgesetzt, dass er nicht entweder hinweggespült oder von Alluvialboden bedeckt ist. Nun lässt es sich nachweisen, dass seit der Zeit seiner Bildung nur geringe relative Niveauveränderungen im nördlichen China stattgefunden haben. Im Grossen und Ganzen was zur Zeit seiner Entstehung die Oberflächengestalt des Landes nahezu dieselbe wie jetzt, das Gesammtniveau aber höher als gegenwärtig, und somit die Kustenlinie weiter in das Meer hinausgeschoben. Der Löss unterscheidet sich daher von allen anderen in ähnlicher Mächtigkeit auftretenden Formationen durch den bemerkenswerth Umstand, das er sich von Anfang an in denjenigen relativen Höhen abgelagert hat, in welchen wir ihn jetzt finden. Seine Bildung fand gleichzeitig in dem tiefen Einschnitt des Hwang-ho und auf den Höhen des Wu-tai-shan-Gebirges statt. Schon diese vorläufige Betrachtung leitet zu dem Schluss, dass der Löss seine Entstehung Bildungsvorgänges verdankt, wie man sie bei anderen, aus ähnlichem Material bestehenden und eine ähnliche Mächtigkeit erreichenden Formationen anzunehmen nicht gewohnt ist."

effectiveness of the wind to special climatic conditions and thus laid the foundation of an intelligent understanding of this extraordinary deposit. It is to be regretted that in his day the criteria of physiographic interpretation had not been developed, else his keen eye had clearly discerned the history recorded in the mountain forms, and we should have had from him a correct interpretation of the later geologic history of Asia.

Origin of materials of the Huang-t'u.—The distribution of the Huang-t'u formation has been described in the preceding chapter, and the reader is referred to that description for those details of occurrence which we observed. In this place we have to present a statement of the conditions of accumulation of the Huang-t'u formation, as we understand them, that accumulation being a chapter in the physiographic history which peculiarly distinguishes the Hin-chóu epoch. Building upon the observations of our predecessors, Pumpelly and von Richthofen, we present the following as the best explanation which we have been able to reach of the complex phenomena.

The first question is the origin of the material of which the Huang-t'u is composed. Its volume and its character are unusual and challenge explanation. Pumpelly attributes the material to secular disintegration of rocks during a prolonged period of climatic conditions favorable to vegetation and rock decay. He says:*

The one weak point in von Richthofen's theory is in the evident inadequacy of the current disintegration as a source of material. When we consider the immense area covered by loess to depths varying from 50 to 2,000 feet, and the fact that this is only the very finest portion of the product of rock destruction, and again that the accumulation represents only a very short period of time, geologically speaking, surely we must seek a more fertile source of supply than is furnished by the current decomposition of the rock surface.

It seems to me that there are two important sources:

I. The silt brought by rivers, many of them fed by the products of glacial attrition flowing from the mountains into the central region. Where the streams sink away, or where the lakes which received them have dried up, the finer products of the erosion of a large territory are left to be removed in dust storms.

II. The second and, I believe, the more important source is in the residuary products of a secular disintegration which we will now consider.

In all regions where the soil is protected by a luxuriant vegetation, the greater part of the insoluble products of disintegration remains *in situ*. Considerable portions of the continents have remained above water during long geological periods. Where this has been the case, and where the region thus exposed enjoyed a peripheral climate with a protecting vegetation and abundant generation of carbonic acid, the feldspathic rocks have been profoundly affected; granite and gneiss being decomposed often to a depth of several hundred feet.

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* Relations of Secular Rock Disintegration to Loess, Glacial Drift, and Rock Basins. American Journal Science and Arts, vol. XVII, February, 1879.

After discussing the residual mantle of decayed material as a source of glacial drift, he continues:

In Northern Asia, north of the 40th degree of latitude, there are no traces of general glacial action such as existed in Northeastern America and Northern Europe. The evidence, indeed, is all the other way. And yet, while the rocks of Southern Asia show extensive residue of disintegration, the results of a secular decomposition protected from erosion by an abundant vegetation, the feldspathic rocks of Central Asia are as free from this as are those of Northeastern America.

The only answer to the question, what has become of them? is that they have been blown and sifted and assorted by the winds, the heavier fragments remaining to be reduced by weathering and to form the stony steppes, the sand drifting in billowy waves over the country, and forming sand deserts, while the fine dust floating in the air, an impalpable powder, is deposited far and near, and under the influence and protection of the steppe grasses is transformed into the loess.

Pumpelly's generalization is sustained by our interpretation of the physiographic history. During the Peï-t'ai and T'ang-hién stages the region under discussion had long been subjected to erosion at a moderate altitude above sea. It had presented a relief not unlike that of the southern Atlantic states, and under similar climatic conditions may well have developed a similar mantle of residual soil or saplite. There is reason to believe that the Peï-t'ai and T'ang-hién epochs belong to the Tertiary period, and that Asia during that time may have shared in the mild and moist climate which is generally assigned to that period. If so, both topographic and climatic conditions were favorable to the accumulation of the products of rock decay over that part of Asia, within which the characteristic features of the Peï-t'ai and T'ang-hién stages had their development. The question of the provincial or continental extent of these features is discussed in the following chapter on systematic physiography, but I may here anticipate the conclusion that they are extensively developed phases of topography.

As the initial step in the explanation of the Huang-t'u formation, we thus assume that prior to the Hin-chóu epoch there existed over a considerable area an adequate supply of the products of secular rock disintegration, which was held in place by vegetation, flourishing under favorable climatic conditions.

Climatic fluctuations.—The next step in the development of our hypothesis of the formation of the Huang-t'u is the assumption of climatic change. In this we follow both von Richthofen and Pumpelly. Von Richthofen discusses the question in his account of the development of the arid basins of Asia,* and resting on the brackish character of the great Sarmatic mediterranean of eastern Europe and western Asia,† and the gradual withdrawal

* China, vol. I, p. 109 *et seq.*

† Neumeyer, Erdgeschichte, vol. II, p. 523 *et seq.*

of that sea during late Tertiary time, he concludes that an arid climate ensued. At the present time we may supplement his hypothesis by adding to the continental causes connected with mountain growth those general causes of climatic change, which are believed to have initiated the cold climate of the Pleistocene.*

Believing that, toward the close of the Tertiary, there was a notable change of climate resulting in pronounced aridity in the interior of Asia, we find therein a sufficient explanation for the destruction of the vegetation and the removal of the mantle of decayed rock. The change is thought to have been one from a mild moist climate to a cold arid climate. Glaciation is excluded by the absence of any deposits, such as would undoubtedly have remained as records if glaciers had developed far beyond the high mountain ridges in which they are now found. The degree of dessication is thought to have been sufficient to give the wind that power which it now possesses as a sorting agent, in those regions where vegetation does not clothe the ground. It does not appear that this necessarily implies a desert condition, since at the present time, in northern China, where crops are successfully grown in many districts every year and in most districts three years out of five, the dust storms produced by the wind have a notable effect in resorting and redistributing the loess. The degree of aridity essential to efficiency of wind action is not inconsistent with the continuance of constant streams in larger watersheds. Under these conditions of effective wind action during a longer or shorter arid season of each year, and of effective erosion and transportation by water during the corresponding season covering the remainder of the year, that is, under climatic conditions similar to those now existing throughout a large part of eastern and northern Asia, both wind and water must have taken part in handling the available detrital material. During the dry season wind would be most effective, and the transported product would be that which was fine enough to be taken up by moving air. During the wet season torrential rains would gather the coarser products of rock decay, and, in brief hours of activity, transport them in large quantities to alluvial cones at the mouths of gulches. In the wide valleys, as on the mountains, the alluvium of the streams would be sorted by the winds and distributed, and the dust accumulations, spread by the winds in the basins and mountain slopes, would be taken up by the waters and redistributed as alluvium. These are the processes which are now interacting in the Loess Basins of Shan-si, and the results are modern deposits of the Huang-t'u formation, which are indistinguishable in lithologic character and structure from the earliest deposits which we saw.

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* Chicago Journal of Geology, T. C. Chamberlin, vol. VII, 1899.

Von Richthofen's theory of the loess does not admit the interaction of winds and streams. He held that during the loess epoch dessication was so complete that the rivers ceased to flow, and wind alone was the sorting and transporting agency. From this extreme view we differ in assigning to rivers a practically continuous, though variable, activity as transporting agents. Had there been times of desert dryness, we should have deposits of desert sands and residual sheets of stony shingle, but these have not been observed in Chï-li or Shan-si.

We recognize, however, certain evidence of climatic changes. The eolian drifts, which occur in the canyon of the Sing-ho and adjacent valleys, are deeply cut by growing canyons. The conditions of removal which now exist can not have been those of accumulation, and the one factor which may have changed is rainfall. With somewhat less precipitation than now occurs, the rivulets which are dissecting the drifts should have been ineffective, and the winds might pile up the continuous mass of loess which has accumulated in the hollow of the hills. Hence we infer a fluctuation of climate; and, since the drifts are younger than the mountains, the fluctuation is one which falls in the latest epoch, the Fön-ho. That other climatic variations occurred earlier in the Fön-ho epoch and perhaps still earlier in the Hin-chóu is highly probable.

This evidence indicates climatic change of a kind and order closely comparable with that inferred by Huntington for the Basin of Sistan, on the basis of river terraces.*

Transportation of the Huang-t'u.—Whenever the climate was sufficiently moist, extensive watersheds must have yielded rivers, perhaps resembling the Huang-ho in size, which flowed from the continental interior to the sea. Among such streams rising in the plateaus of Mongolia, we would name the Hu-t'o-ho in its course as far down as Hin-chóu, and further through the Shï-ling to the Fön-ho valley. With our present meager knowledge of details of geography in northern Shan-si, we are unable to point to any other similar streams, but it is quite possible that stretches of the upper Huang-ho date from an early time, and that there were other streams flowing in a general southwest course, such as we have traced in our descriptions of the T'ang-hién epoch.

Flowing from an area which was in process of elevation, and which was subject to climatic conditions extremely favorable to a rapid denudation, such rivers must have been heavily loaded with silt, a large part of which differed from that commonly received by streams in having been thoroughly sorted by the winds and in being, therefore, the characteristic

* Explorations in Turkestan, Expedition of 1903, under the direction of Raphael Pumpelly. Carnegie Institution of Washington, Publication No. 26. The Basin of Eastern Persia and Sistan, by Ellsworth Huntington, pp. 273 *et seq.*

material of the loess. In the course of its transportation down the valleys, from the inner basins, from which it is supposed to have been sorted, to the lowlands where it is now found, it was spread again and again upon the flood-plains of the streams, and in the alternation of the seasons was continually subjected to the process of sorting and re-sorting, which is still going on under similar conditions. In so far as the valleys in which it was deposited were environed by hills and mountains, the loess proper was liable to interstratification with the detritus of alluvial cones washed from the hillsides. These two constituents of the Huang-t'u formation, the loess, which is the eolian product, and the gravels and sands, which are the fluviatile products, were brought together by the joint and alternating activities of the winds and streams.

Physical characters of the Huang-t'u.—The manner of accumulation of the loess formation has been frequently discussed on the basis of its peculiar characters: constitution, texture, and structure. In the preceding paragraphs the sorting and reassembling of the mechanical constituents has been sufficiently described. The salts which, through their abundance and constant renewal, render the Huang-t'u unusually fertile, next demand consideration. They are not accounted for by the activities of winds and rivers, for we would suppose that fine material such as the loess must become thoroughly decomposed and leached in the alternating processes of wetting and drying, sorting and transporting, to which it has been subjected during the Quaternary. In fact loess is composed of chemically obdurate substances: quartz, silicate of alumina, and oxide of iron; yet these are associated with soluble carbonates, sulphates, and chlorides of the alkaline earths and alkalies. These salts may be regarded as secondary constituents derived from ground water.

In a deposit of Huang-t'u during alternate seasons of moisture and drought, the movement of ground water is probably intermittent. If we suppose a mass to be deposited dry, or to have been dried out during a period of general dessication, it must absorb a large volume of water from rains of a succeeding season or episode. The pore space in fine alluvial clays of this sort is at least from 40 to 60 per cent of their volume.* Rains are promptly taken up by the Huang-t'u, from which there is almost no run-off, but they can moisten the mass to a considerable depth only if long continued, since large pore space and evaporation limit their penetration. Thus the lower part of the mass may long remain dry, so far as wetting from the surface is concerned. But beneath the Huang-t'u, at the contact with the underlying rocks, is a surface on which waters flow from the adjacent mountain slopes.

* C. S. Slichter. 19th Ann. Rep., U. S. Geol. Surv., Part II, 1899. Van Hise, Treatise on Metamorphism, p. 125.

Von Richthofen says:*

One of the consequences of the vertical arrangement of capillary texture is that the loess takes up water like a sponge. The heaviest rains leave only slight traces upon the surface, therefore no puddles remain standing; and for the same reason there are, in the true loess deposits, no lakes. I never saw a spring flow from it; they first occur in number there where the loess rests upon the hard rock.

Coming in contact with a dry mass of loess, underground waters should be energetically absorbed and carried upward by capillary attraction. Being the run-off of larger or smaller areas of steep mountain slopes, and being subject, in their subterranean position, to the major changes of seasons only, they should be more copious and more constant than the waters entering at the surface of the Huang-t'u. We may thus consider the dry mass as becoming charged with moisture from both above and below, but in larger degree from below. If sufficient moisture be supplied the two moistened parts would meet and the whole mass become damp.

The ground water, thus entering the Huang-t'u, carries with it a proportion of salts derived from the rocks. In northwestern China the bed-rock over very large areas is limestone, and the Huang-t'u is known to contain large amounts of carbonate of lime, both as a generally distributed constituent and in nodules. Concentration from ground water occurs in soils as a result of evaporation and through absorption and chemical reaction. The conditions can only be suggested here. For a fuller account the reader is referred to articles by Way,† Warington,‡ and Van Bemmelen.§ From their experiments it follows that the inorganic colloids, such as silicates of iron and alumina, absorb the alkaline earths and alkalies from salt solutions (chlorides, nitrates, and sulphates) in exchange for the base of the colloid. Hydroxide of iron absorbs soluble salts in consequence of their diffusion in the water which it contains. Colloid silica takes alkali from alkaline solutions of carbonates and also lime from carbonate of lime. The presence of carbonate of lime promotes the decomposition of potash salts with the formation of a lime salt with the acid and the absorption of potassium hydrate by the silica. The Huang-t'u formation being made up of the silicates of iron and alumina, hydroxide of iron, and silica, all of which are probably present in large amounts as colloids, the conditions for these reactions are favorable and the formation

* China, vol. I, p. 58. "Eine der Folgen der senkrecht angeordneten capillaren Textur besteht darin, dass der Löss Wasser aufsaugt wie ein Schwamm. Die stärksten Regengüsse lassen nur geringe Spüren auf seiner Oberfläche. Es bleiben daher keine Tümpel stehen, und aus demselben Grund gibt es auch auf eigentlichem Lössboden keine Seen. Quellen sah ich nie in ihm entspringen; sie treten erst dort in Menge hervor, wo der Löss dem festen Gestein auflagert."

† Way. Journal Royal Agricultural Society of England, vol. XI, p. 313, and vol. XIII, p. 123.

‡ Warington. Journal Chemical Society of London, vol. XXI, p. 1, 1868.

§ Van Bemmelen. Zeitschrift für anorganische Chemie, vol. XXIII, pp. 358–364, and vol. XLII, p 314.

may become charged with the salts taken from ground waters which rise by capillary attraction within the mass. When the waters fluctuate in consequence of periods of dryness, the salts in the colloids would remain and an additional amount would be deposited by evaporation.

The distribution of the loess-männchen, or calcareous nodules, bears on the conditions of deposition from ground water. The nodules occur in horizontal layers, with their longer axes vertical. Von Richthofen says:

> Only the loess-mannchen are arranged in special horizontal layers. If, however, one examines such an apparent bedding plane, it appears that all these concretions stand with their longer axes vertical. They must, therefore, have developed in the place and position in which they are found.*

In alkali soils which become saturated with ground water and suffer evaporation, a continuous layer of hard calcareous deposit commonly results. The loess-männchen, being discrete and widely distributed, appear to have segregated under conditions of less complete saturation of the porous mass. It is conceived that they represent centers of aggregation, set up at appropriate intervals in horizontal spacing and built up and down vertically according to the control of capillarity, of gravity, and oscillations of the surface of moisture.

That the ground water in the Huang-t'u generally falls short of saturation is rendered probable by the behavior of loess in contact with abundant water. It puddles readily, becomes practically liquid, and flows *en masse*, leaving a vertical well or tunnel if the wet loess be surrounded by dry. This capacity to flow is due, as has been stated to me by Prof. C. S. Slichter, to the fact that any solid particle, whose diameter is less than the thickness of a capillary film of water, may enter that film and, becoming part of the liquid, flow with it. Were a body of loess to become sufficiently saturated with water it would be transformed into a liquid mud, which could not possibly remain in many of the situations in which it is found. An instance of a landslide, which we may attribute to saturation of the loess, was observed about 4 miles, 6.5 kilometers, east of Hua-chóu, Shen-si, at the base of the Ta-hua-shan. For three-fourths of a mile, 1 kilometer, parallel to the front of the mountains and out to 2 miles, 3 kilometers, from their base the level plain was covered with low irregular mounds of loess and angular rock masses. The latter were from 10 to 15 feet, 4.5 meters, in diameter and were imbedded in fine loess above the general level of the plain. Among the hillocks were marshy hollows. The mountain slope opposite this occurrence was bare of the loess, which elsewhere

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* Von Richthofen, China, vol. I. p. 61. "Nur die Lössmännchen sind in besonderen horizontalen Lagen angeordnet. Untersucht man jedoch eine solche scheinbare Schicht, so zeigt es sich, dass alle diese Knauern mit ihren Längsaxen senkrecht gestellt sind. Sie müssen daher an Ort und Stelle entstanden sein."

covered it, and there seems no doubt but that the huge rocks rode out on to the plain on the loess, which could only move in that manner if saturated, but in that state could flow and transport them, even 2 miles. Where the Huang-t'u extends below the level of ground water, as in river flood-plains, it no doubt is a reservoir holding a very great volume of water in its pore spaces; but when it accumulates above ground water, or is drained as that level is lowered by lowering of the point of discharge, then it usually remains unsaturated, though perhaps moist from top to bottom.

The vertical cleavage of the Huang-t'u is one of its most general and conspicuous characters. The view expressed by von Richthofen and accepted by Pumpelly, that it is due to pores left by the decay of grass roots, may hold in districts where the steppe grasses prevail and for deposits on which they have grown continuously, but it does not suffice to explain the structure in masses laid down under the varied conditions of the Huang-t'u in China: where climatic conditions have been from time to time more or less arid; where the surface has at times been that of a drift or of a flood-plain, or of a lake bottom; and where the structure extends from top to bottom of every mass, however thick, and is coextensive with the formation over hundreds of square miles. Grasses which should be so universal and so persistent as is this structure would excite wonder.

We saw the vertical cleavage in masses that were stratified, as well as in those that were not stratified; in water-laid and wind-drifted deposits; in plains and on mountain slopes; in older and younger accumulations. It thus appears to be independent of conditions of deposition, site, and age. It does not occur in unconsolidated drifts of recent dust storms; it is uncertain whether it would be found in Huang-t'u which extends below ground water level, but it does occur in dried, *i. e.*, consolidated, deposits of Huang-t'u, of whatever genesis. It is better developed in wind drifts which are composed wholly of loess than in water-laid bodies that include appreciable amounts of unsorted residual clays; thus it seems to be related to texture. Texture and consolidation seem to be the governing factors in its development. Von Richthofen says:*

> There can be no doubt that this remarkable phenomenon of the tendency of loess to a vertical parting has its origin in the peculiar vertical capillary texture.

Agreeing with him in this conclusion, but finding the theory of grass roots altogether inadequate, I suggest the following activity of physical and chemical processes induced by gravity, capillary attraction, and cementation, through the medium of moisture and the fine earthy particles. A

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* China, vol. I, p. 61. "Es kann keinem Zweifel unterliegen, dass dieses merkwürdige Phänomen, der Tendenz des Löss zu einer verticalen Absonderung, in der eigenthümlichen verticalen Capillartextur seinen Ursprung hat."

body of Huang-t'u, whether water-laid or wind-drifted, is very porous. The porosity may be partially due to removal by water of subcapillary grains of loess after consolidation, but is in greater degree an original condition. In alluvial Huang-t'u the interstices were originally occupied by water. In eolian Huang-t'u air filled them; and so long as the air continues dry, the deposit remains incoherent and structureless, as one may see in newly formed drifts during cold weather. A footprint in such drifts resembles one in dry, powdery snow.

Whatever the original condition, whether wet or dry, the Huang-t'u settles, at least during an early stage of consolidation. Under the influence of gravity all interstitial spaces lessen, and interstices which approach a horizontal position must be narrowed more than any which approximate verticality. Theoretically the resulting structure should exhibit linear openings at angles of 45° to the horizontal, if the grains were spherical and of uniform size,* but since they do not fulfil this condition that structure is likely to be very imperfect. The effect of gravity is to bring the irregular particles in closer contact so far as they rest one above another, and to leave them in more open order so far as they lie side by side. Interstitial air or water is forced into the more open spaces, and in any movement follows the upward-downward lines of least resistance.

The Huang-t'u contains two classes of material which tend to cement surfaces on which they may be left: the fine loess particles and the chemically dissolved salts of the ground water. Let us suppose that a mass which was either deposited wet, or which has been moistened by rain and capillary elevation of ground water, becomes dry. Evaporation from the surface may cause moisture to rise, leaving a dry mass below if the underflow is checked; or lowering of ground water may leave a dry layer above. In either case the moisture in the capillary spaces will coat the walls of those spaces with a paint of the finest loess particles and with a deposit of salts left by evaporation. There will be a tendency to close the smaller interstices, those approximating a horizontal attitude, and the larger up-and-down ones will be left comparatively open. If the mass be moistened or wet again, they will become the channels through which moist air or water will move; they may to some extent be opened by softening of the loess paint or solution of the salts; and they will be coated again when the mass again dries out. It is conceived that repetitions of this process give rise to the rudely vertical tubes described by von Richthofen, and thus produce the tendency to vertical cleavage.

It is to be noted that cleavage of the Huang-t'u is imperfect. If we regard the inequalities of the structure in comparison with the fine grain

* Slichter, *loc. cit.*

of the material, we find them large and the surfaces of cleavage irregular. The irregularities increase as the proportion of loess decreases, and pass into the characteristic fracture of a bank of residual loam when the proportion of loess becomes insignificant. It is probable that the structure is perfected through a certain amount of drying and wetting, and it is possible that it may be impaired or lost by too long-continued or too frequent wetting. Should the flow of water through a body of Huang-t'u suffice to remove most of the loess particles of capillary or subcapillary diameter and the salts, the remaining mass would approach a loam of relatively coarse texture. The cementing substance being taken away, the residuum would be more or less incoherent and would fail to maintain a vertical structure.

The cementing, which is occasioned by the evaporation of moisture in the Huang-t'u, is the occasion of its endurance in steep walls. Not that the cement itself is very firm (it is but a film of loess paint and salts), but it is so arranged in the mass as to give great strength, the weakness of the substances being considered. Each tubelet may be regarded as a self-supporting element, or each rudely vertical and cemented column of particles may be considered as such. If the mass is permeated with moisture and the cement is dissolved, the structure remains firm because the interspaces are filled; if the moisture retreats, the cement is redeposited and the mass continues to stand fast. The structure is maintained because ever renewed, unless the amount of water is sufficient to supersaturate the body; then it flows like a liquid.

Geographic features.—The altitude of the land during the Hin-chóu epoch may be inferred from the relations of the Huang-t'u formation. During the preceding T'ang-hién epoch it had been low, yet such that degradation had not ceased. The district in Shan-si had also, like other areas of northern central Asia, presumably been subject to a moist climate, and had presented a surface of decayed rock, saplite. At the present time the surface on which the Huang-t'u rests is not deeply decayed; on the contrary, the rocks are fresher than one would expect, until one reflects on the climatic conditions which have reigned throughout the Huang-t'u epoch. It follows that any mantle of saplite which may have been (and probably was) present when the T'ang-hién epoch of moist climate passed into the Hin-chóu epoch of aridity, was, to a greater or less extent, eroded before the Huang-t'u was laid down in Shan-si. The plains where the Huang-t'u is now being deposited by rivers are situated near a local or general base-level, and it may be assumed that the same condition governed during the Hin-chóu epoch. Combining these considerations, we are led to infer that in Shan-si and Chï-li altitude and climate favored erosion of saplite during the early Hin-chóu time, and in the same region depression favored the accumulation of the Huang-t'u during later Hin-chóu

time. We conceive that the valleys of the Fön-ho, Hu-t'o-ho, and other streams of northern Shan-si and Chï-li were covered by flood-plain deposits during a gradual subsidence, and the hills were buried as they sank till they were partially or wholly submerged in the Huang-t'u formation, as they are now in the typical district about T'ang-hién.

If the preceding inductions are correct, eastern China was margined in Hin-chóu time by a plain, consisting of the confluent flood-plains of the streams flowing from the interior of the continent and bringing voluminous loads of loess and alluvial sand. These flood-plains extended northeastward over the present site of the northern Loess Basins. To what extent they may have inclosed mountainous islands or promontories such as Shan-tung now presents, we are unable to determine with accuracy; but it is probable that such islands existed with moderate relief, though perhaps of considerable extent. There are areas, such as the summits of the Wu-t'ai-shan, which have not been deeply eroded since the T'ang-hién epoch or an earlier time, and which are covered with residual soil. We may regard this soil as a remnant of that mantle of saplite which cloaked the surface during the Peï-t'ai and T'ang-hién epochs.

As the process of subsidence and aggradation proceeded, and the relatively shallow valleys filled till their flood-plains became confluent, conditions became peculiarly favorable to rearrangement of streams. The method of readjustment has been sketched in describing the Hang-ho. The effects are clearly recognizable in the growth of rivers, whose southeastern courses are at right angles to the southwestern courses of the older systems. The Hang-ho, the Sha-ho below Fóu-p'ing, the Hu-t'o-ho below Tung-yü, the Sing-ho, and the Shï-t'ou-ho (atlas sheets F I, E I, and C I, and Plate II) are streams which are believed to have developed their present courses in consequence of aggradation. The cause of their growth is thought to have been a slight southeastward tilting, sufficient to determine the slope of the confluent plains in the direction in which the streams now flow. The rivers are regarded as consequent upon that slope. With reference to buried ridges, which they discovered as they sank their channels, they are superimposed streams—the Hang-ho and possibly the Sha-ho exhibit such features in the Ning-shan district—and with reference to the later mountain growths of the Fön-ho epoch they are antecedent.

It is possible that tilting and development of consequent streams antedated the aggradation of the surface, and that the growth of the present southeasterly courses should be assigned to the close of the T'ang-hién epoch. The topography of the mature surface was no doubt then favorable, and the suggestion finds support in the fact that such valleys as that of the Sing-ho appear to have been cut out with a southeast course

before being filled with the Huang-t'u. There are two considerations which render any conclusion indeterminate: (1) The valleys of the T'ang-hién stage had reached such advanced maturity that in soft rocks the ridges between them were reduced to monadnocks or groups of monadnocks, among which any valley now filled by Huang-t'u might seem to have been continuous on the rock surface. And (2) the Huang-t'u, now occupying such a valley, is not distinguished by any marks of age that enable us to say whether it is of the first deposit or of a later one. If it is not of the first or early Hin-chóu deposit, the Sing-ho may have extended its valley on an older surface of Huang-t'u; may have eroded that formation and worked on bed-rock; and may have aggraded its valley again—all in consequence of fluctuations of climate during the Quaternary. Until the history of the Huang-t'u is better known, we may not with confidence assign events connected with it to specific times.

The considerations of the preceding paragraph do not, however, affect the inference that the streams, which during the T'ang-hién epoch had flowed southwesterly, were diverted to southeasterly courses before or during the Hin-chóu epoch; that is, before the beginning of the Fön-ho, epoch.

FÖN-HO STAGE.

The Fön-ho stage was characterized by profound mountain growth, involving both surface warping and normal faulting. We attribute to it the development of the Wu-t'ai-shan, the Ki-chóu-shan, the Ho-shan, the O-shan, the Föng-huang-shan, the Ta-hua-shan, and the Ts'in-ling-shan. The altitudes of these ranges vary from 6,000 to 10,000 feet, 1,800 to 3,000 meters. They are culminating crests of the mountain region of Chï-li, Shan-si, and Shen-si, and the elevation of these crests includes also the elevation of the lesser masses which extend beyond them. If our interpretation of the preceding Hin-chóu epoch be correct, altitudes, prior to the Fön-ho epoch, rarely exceeded 1,000 feet, 300 meters, and were generally but a few hundred feet. Thus, whether we consider the mountain growth with reference to the amount of altitude gained or area over which the movement extended, the effects are of the first magnitude.

In seeking a name by which to designate the epoch of mountain growth characterized in the preceding paragraph, one's thought turns at first to one of the great mountain ranges as presenting the most characteristic and obvious suggestion of the dominant activity of the time; but any such range is marked by special features of structure or form, which are more or less peculiar to it, and the use of its name might, therefore, seem to give that special character to the mountain movements. The Fön-ho is a stream which antedated this epoch, which has been modified

by effects of warping, and which flows among some of the most striking ranges. It seems, therefore, to furnish the name which, better than any other, may serve to designate the time during which the river itself was affected and during which the great mountain growths that parallel its valley were developed. Accordingly, we name the recent epoch of dominant mountain growth in northwestern China the Fön-ho epoch.

The features of the Fön-ho epoch are elevations and canyons. The attention is naturally attracted by the great elevations and by the deep canyons, but dimension is not one of the characters by which we may discriminate the features of the stage. The elevation may be slight and the canyon will be correspondingly shallow; or the elevation may be great, even as we speak of the greatest mountains, and the canyon will be correspondingly deep, even among the most profound of gorges.

Features of the Fön-ho stage are characterized by youth and may also be distinguished by their relations to surviving surfaces of earlier epochs. The youthful aspect of the canyons is obvious in the field and it may also be noted in the topographical maps of the atlas as well as in several illustrations of this volume.

The vigorous autogenous valley of the upper Sha-ho; the inner canyon of the T'ai-shan-ho—both in the Wu-t'ai schists and Sinian limestones; the canyons of the Shï-t'ou-ho, Sing-ho, and Hu-t'o-ho in the eastern Ki-chóu-shan; the gorge of the Fön-ho between Ling-shï-hién and P'ing-yang-fu—these are plainly young valleys which have not yet progressed beyond the initial stage of development, that of vertical incision.

Similarly, the southeastward slope, in which the upper Sha-ho valley is growing; the warped surface south of the Loess Basins; the fault-scarps of the Ki-chóu-shan, Ho-shan, O-shan, Föng-huang-shan, Hua-shan, and Ts'in-ling-shan, and the warped surfaces into which they pass; the upwarp across the valley of the Fön-ho between Ling-shï-hién and P'ing-yang-fu, and that which caused the westward diversion of the lower Fön-ho—these are all steeply inclined surfaces, which, whether they be fault-scarps or surfaces due to erosion on warped slopes, are now being attacked by autogenous consequent streams, whose growth is still very moderate. Considering the declivities, the limited development of ravines implies very recent warping and faulting, and the implication is strengthened by the apparent persistence of the Huang-t'u deposits on some warped surfaces. A qualifying factor, which tends somewhat to lengthen the estimate of time since warping and faulting began, is found in the aridity of climate, which lessens the effectiveness of corrasion. The value of this factor is probably large, and it serves to keep any estimate of mountain growth within normal limits, which it might otherwise transgress.

In usual relations features of the Fön-ho stage are cut within valleys of the T'ang-hién and Hin-chóu stages. For example, in the Wu-t'ai-shan we may observe, in sequence from above downwards, the Peï-t'ai surface, the valleys of the T'ang-hién stage, and the canyons of the Fön-ho stage. Similarly, in the Ki-chóu-shan we see the mature topography of the T'ang-hién epoch, still in part covered with the loess of the Hin-chóu, but deeply cut by the canyons of the Fön-ho time. A similar relation holds on the Fön-ho between Ling-shï-hién and P'ing-yang-fu, where the river cuts its channel across the upwarped T'ang-hién surface that is covered with the Huang-t'u formation. A less familiar though not unusual relation exists between the warped slopes or fault-scarps of the Fön-ho stage and adjacent surfaces of older stages. The latter have been, so to speak, thrown by the warping or faulting; they have been elevated or depressed, tilted or dislocated. The tilt or dislocation is a characteristic acquired in Fön-ho time, which serves to differentiate the warp or scarp from the not-warped or not-faulted areas. The warps, which, as they become dissected, lose their earlier topographic aspects, thus take on a phase peculiar to the Fön-ho stage. This phase is cut upon the older features within the tilted areas, but if considered in relation to adjacent areas is seen to form a connecting slope between the elevated and depressed sections, which still exhibit features of earlier stages. This relation is seen in descending from the Wu-t'ai-shan to the Loess Basins. Leaving the Peï-t'ai surface and the ridges which represent the T'ang-hién stage, we pass down over a warped surface that is cut by ravines of Fön-ho time, to the aggraded valleys of the T'ang-hién and Hin-chóu stages.

Such warping and faulting of a topographic surface introduces into physiographic studies problems of identification not unlike those met in tracing folded or faulted strata.

We may now enumerate some of the features assigned to the Fön-ho epoch. It should be borne in mind throughout that the topographic phase preceding the Fön-ho is believed to have been one of very mature relief, and that the valleys had been extensively aggraded with the Huang-t'u formation.

Along the line of our route from Pau-t'ing-fu to Wu-t'ai-shan the valley of the Sha-ho in northwestern Chï-li above Fóu-p'ing-hién, especially above Li-yüan-p'u, first suggested the recency of mountain growth. Its obvious autogeny and the vigorous development of the gulches occupied by its headwater rivulets, as well as the aggressive attitude of the Sha-ho with reference to the Ts'ing-shui-ho, are characteristic of a stream which is growing on a recently warped slope. The fact that so aggressive an agent had not yet succeeded in cutting back into the older valleys of the mountains indicated that it had not long been actively engaged in its

task, and yet its deep canyon-like valley and the ragged ridges which surround it showed that it had most effectively attacked the slope in which it had grown.

When we stood on the summit of the divide between Chï-li and Shan-si and saw the features sketched in Plate XXX, it was clear that, within the record of the older phases of topography, the characters of the most recent uplift and canyon development were inscribed. The typical canyons of the Fön-ho epoch in the Wu-t'ai-shan and in the limestone plateau south of Wu-t'ai-hién are clearly shown in Plates IV and XX. Their relation to the features of the T'ang-hién and Hin-chóu epochs is well expressed in the contours of atlas sheets E I and D I, and may be seen in the photograph of the mountains south of Wu-t'ai-shan, atlas sheet C II. It may be noted that the canyons of the rivers flowing from the Loess Basins do not extend into the basins themselves; that is to say, features characteristic of the Fön-ho epoch are limited to the zone of mountain uplift, and this zone is thus differentiated in regard to relative movements from that of the Loess Basins. Where we find the mountains and canyons there has been relative upward movement; where we find only the features of the preceding epochs there has been relative downward movement, and the rivers which flow from the latter areas into the canyons across the former areas are considered to be antecedent streams which have held their courses.

In describing the relation of the Hin-chóu basin to the basin of Huang-t'u-chai it was pointed out that the Shï-ling pass, which lies between the two, presents the characteristics of a wind gap, presumably from the diversion of the headwaters of the Fön-ho. These headwaters now constitute the Hu-t'o-ho, which is believed to have formerly flowed through the Shï-ling. The diversion is attributed to the differential movement of the Hin-chóu basin, which was downward, with reference to that of the Ki-chóu-shan and the Shï-ling, which was upward. The face of the Ki-chóu-shan toward the Hin-chóu basin is characterized by the features of a great fault-scarp, a typical development of Fön-ho time. The youthfulness of the scarp is shown in the moderate development of consequent ravines and in the fact that ridges, formed during the earlier episodes of faulting, are cut off by the plane of later faulting. Associated with the growth of the fault-scarp, both on the northeast and southwest where it runs out, are warped surfaces on which one may still trace the features of the preceding epoch, now tilted, however, to an attitude in which they are being vigorously dissected. The canyons by which the antecedent streams leave the Loess Basins and flow across the mountains enter this warped surface and deepen gradually as they pass into it. At the Shï-ling the upwarp is covered with loess, which may be in part modern wind

drift, but is probably also to some extent original, and which, under present conditions of slope and climate, is now being eroded, as is shown by the numerous deep gullies that reach into it.

The basin of T'ai-yüan-fu and the mountain ranges which surround it present features identical in general aspects and relations to those of the more northern Loess Basins and their environing mountains. The basin, which is deeply filled with the Huang-t'u formation and which contains, no doubt, extensive deposits of that formation from the earliest to the latest, is regarded as a downwarp of the Fön-ho epoch. The mountains which lie along its northwest margin show a tilted surface of older topography, which is now being dissected, but which has not progressed far toward the ultimate obliteration awaiting it. On the southeast side of the basin a similar warped surface rises to the mountains, which are the northern extension of the Ho-shan. From that upwarp the fault-scarp of that great range extends south, having the same genetic relation to the warped surface which the fault-scarp of the Ki-chóu-shan possessed to the warped surface from which it springs.

The valley of the Fön-ho, considered with reference to the upwarp of the Ho-shan and the O-shan, is a graben. Our reason for assigning the sinking of the graben to the Fön-ho epoch is that the fault-scarp of the Ho-shan so far as we could observe it, and that of the O-shan as described by von Richthofen, have only suffered a degree of erosion of the same order of development as that of the Ki-chóu-shan.

Across the valley of the Fön-ho, extending in an east-west direction between Ling-shï-hién and P'ing-yang-fu, is the upwarp through which the Fön-ho, as an antecedent stream, has cut the canyon that the highway avoids by crossing the high passes of the Si-sin-ling and Si-yau-ling. Although we did not see the deeper parts of this canyon, its character south of Ling-shï-hién, where it is 400 feet, 120 meters, deep, in relation to the features of the T'ang-hién and Hin-chóu epochs which characterize the uplands, sufficiently mark it as belonging to the Fön-ho epoch.

The basin of P'ing-yang-fu and the lower portion of the Fön-ho valley constitute a depressed area in the southern part of the graben of Shan-si. They present no distinctive features which would enable us to assign them to any time later than the Hin-chóu epoch, but they are surrounded by upwarps of the Fön-ho time.

The ridge which extends east and west, south of the junction of the Fön-ho and the Kü-ho, is one of the youngest features assignable to the Fön-ho time. It has an elevation of about 1,200 feet, 365 meters, is still covered by the Huang-t'u formation, and is characterized by the extreme youth of the autogenous gulches which are being cut in the mantle of

soft alluvium. Its relation to the ancient valley of the Fön-ho, from which that stream was diverted in consequence of the upwarp, and its value as an evidence of the very recent activity of mountain growth in this region, have been stated.

The Fön-ho epoch is the latest of the physiographic stages of northwestern China. Its features belong to the immediate past and the present. That active mountain growth by which it is characterized continued to a geologic yesterday; whether it is active or quiescent to-day or will be in a geologic to-morrow is indeterminable.

CORRELATION OF PHYSIOGRAPHIC STAGES.

The position of the successive stages in the geologic time scale is debatable. If we reckon from the latest deformation the epochs to be considered are:

(1) The Peï-t'ai, comprising much or all of the time following the Post-Paleozoic folding, and sufficing for complete erosion of the mountain heights due to development of the great anticlinoria and synclinoria noted both in northern and central China. The resulting surface was one of advanced old age, and the cycle of erosion was unquestionably long.

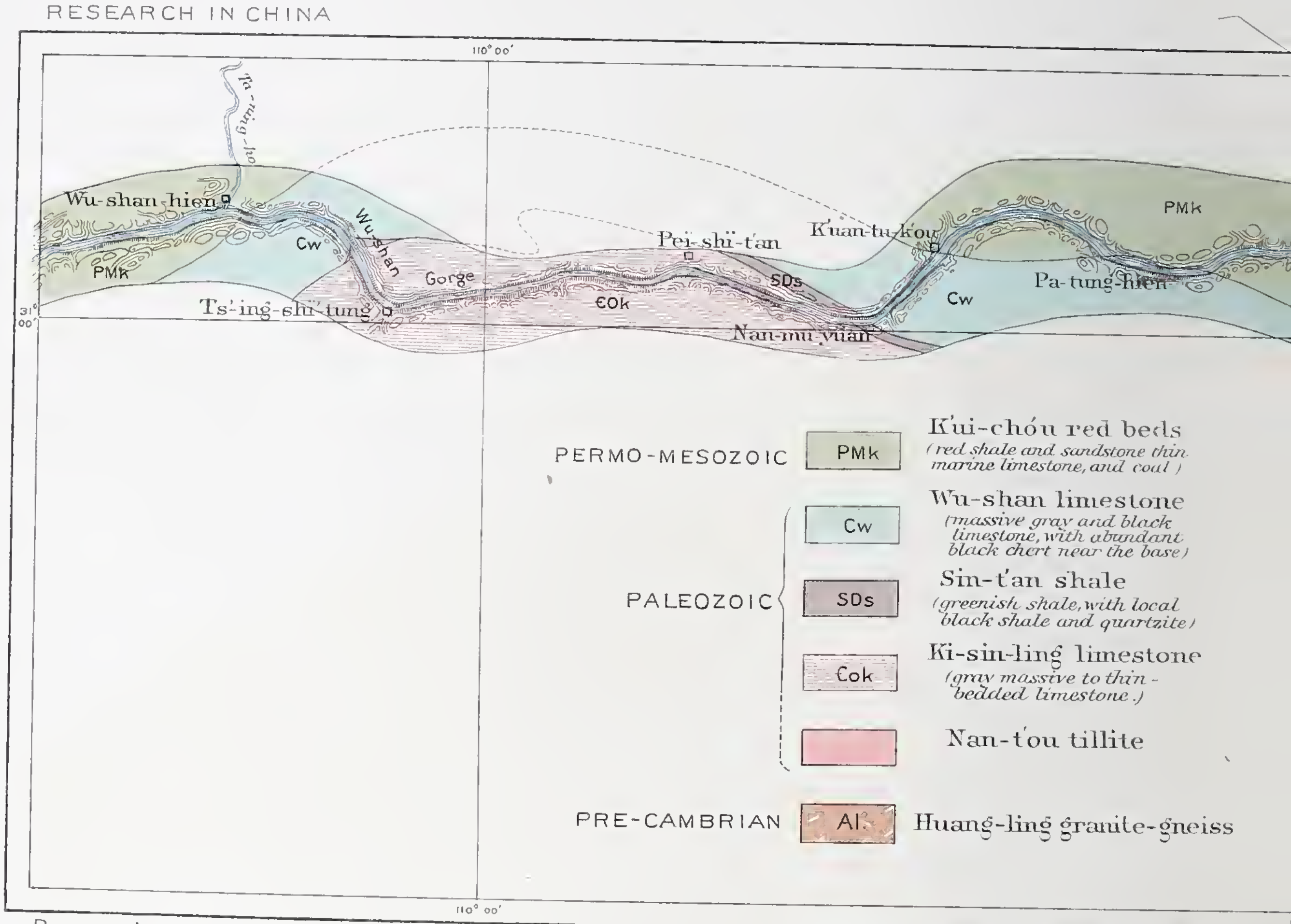
(2) The T'ang-hién epoch, not so prolonged as the Peï-t'ai, yet long enough to produce a warped and faulted surface and to reduce it to advanced maturity, with surviving relief of 500 to 1,000 feet, 150 to 300 meters.

(3) The Hin-chóu epoch of aggradation, involving climatic change and extensive degradation in central Asia.

(4) The Fön-ho epoch of mountain growth, which has resulted in differences of elevation of 7,500 to 10,000 feet, 2,000 to 3,000 meters, or more.

The following is a provisional assignment of these epochs to geologic periods on the evidence now available.

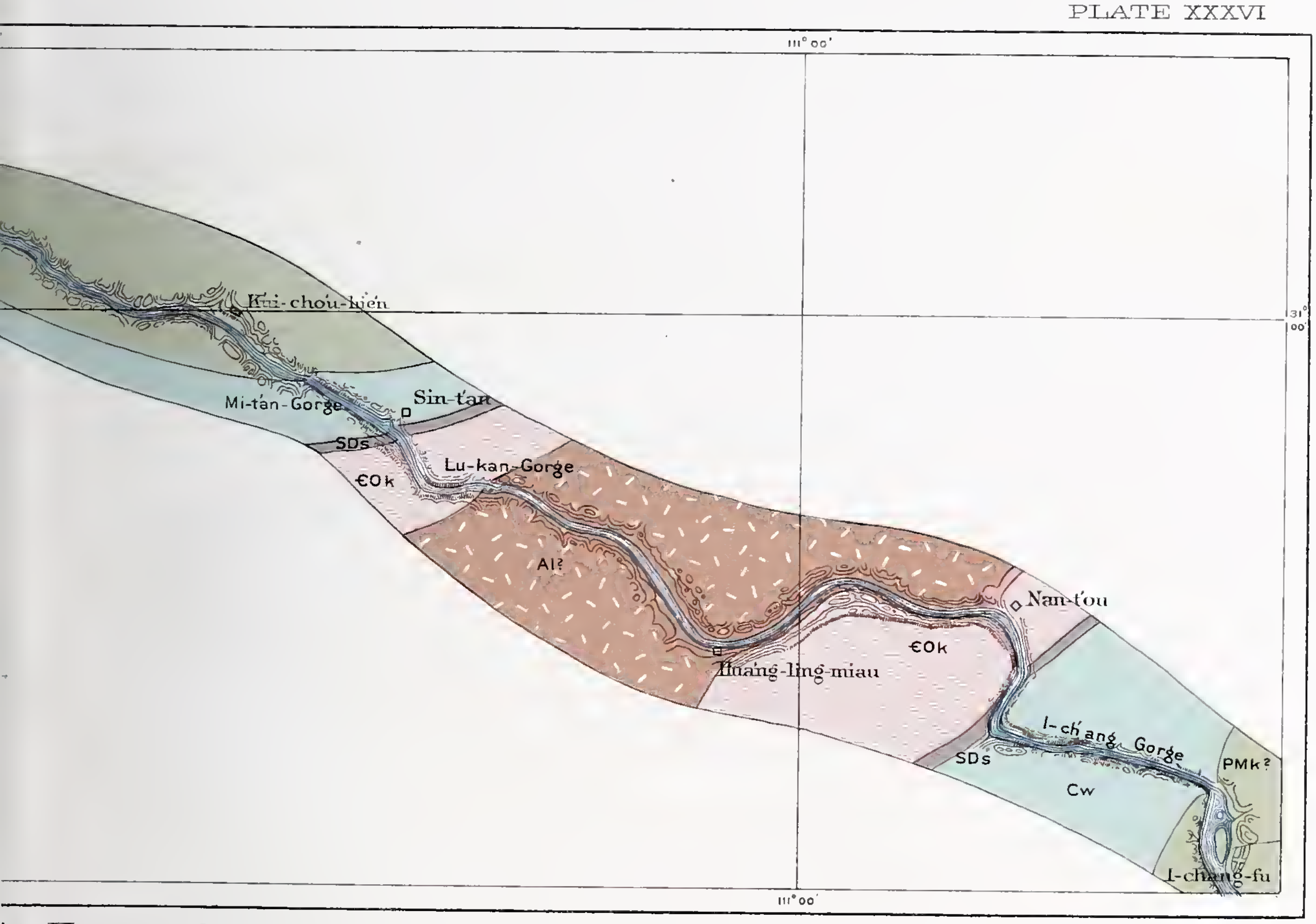
The cessation of Post-Paleozoic deformation can not be positively fixed; it may be early or middle Mesozoic—not later than the middle of the Jurassic. Beginning then, the Peï-t'ai cycle extended through the Cretaceous and probably well into the Tertiary; the T'ang-hién cycle may be assigned to early and middle Tertiary, including probably also part of the Pliocene; the climatic change and aggradation of Hin-chóu time followed during later Pliocene, and the succeeding Fön-ho epoch covers the Quaternary.



Base reduced from map of the upper Yang-tzï
by R.P. Le Chevalier

Geological Map o
Wu-shan-hien, Ssï-c
by Ba
Scale
0 1 4 8 1
0 4 8 1

PLATE XXXVI



A. HOEN & CO. BALTIMORE

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n to I-ch'ang, Hu-peï
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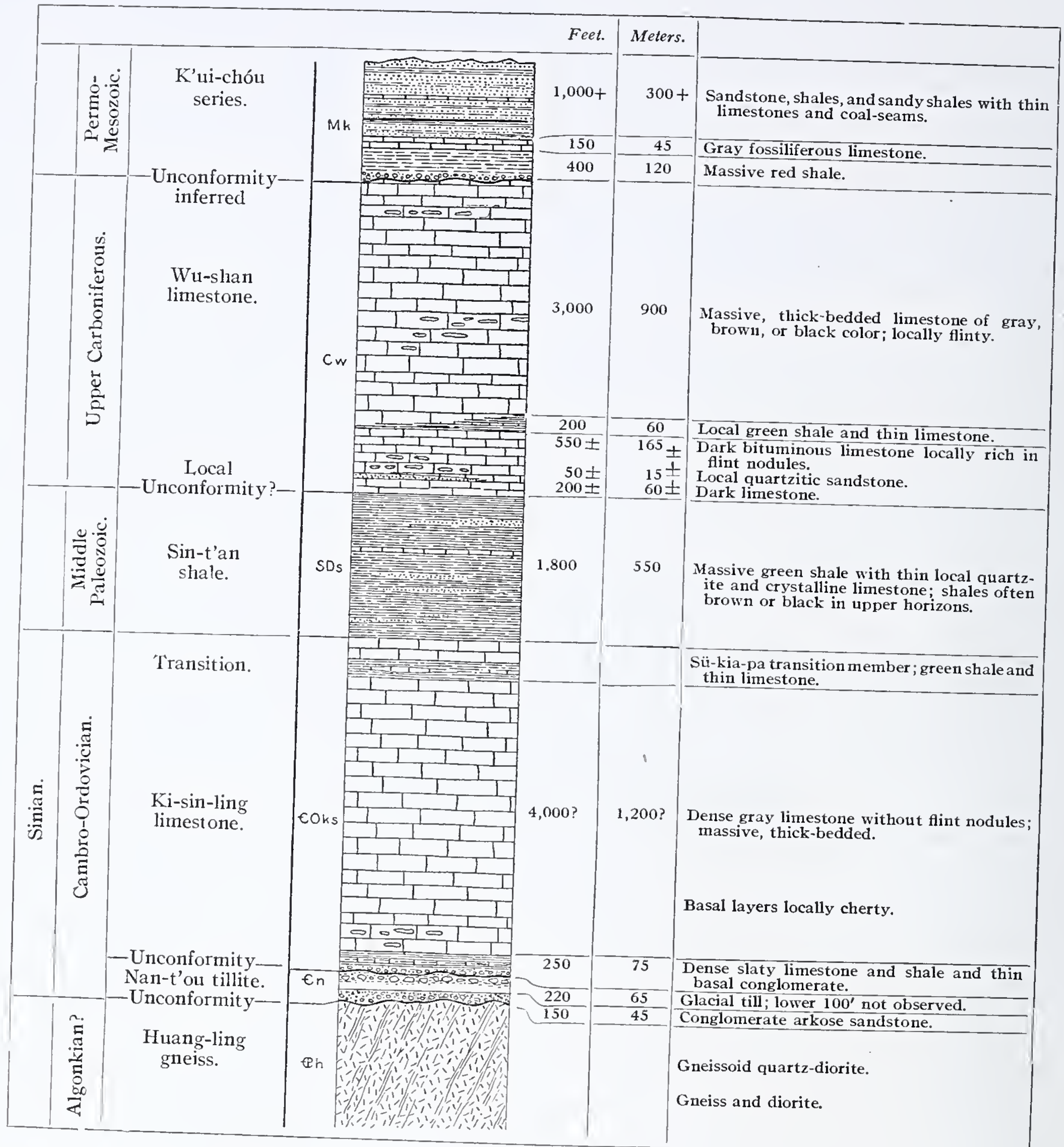
SECTION III

CENTRAL CHINA

PROVINCES OF

SSÏ-CH'UAN AND SHEN-SI



Total.........................11,970 3,600

FIG. 59.—GENERALIZED SECTION OF FORMATIONS IN EASTERN SSĬ-CH'UAN AND LOWER YANG-TZĬ GORGES.

CHAPTER XII.

STRATIGRAPHY OF THE MIDDLE YANG-TZÏ PROVINCE.

BY ELIOT BLACKWELDER.

This chapter and the one on structure, which follows, relate to what may be called the province of the middle Yang-tzï, the geologic features which characterize the region being typically developed along the watershed of that great river in its middle section, below the junctions of its principal headwaters and above the lower course in its vast flood-plain; that is, between Chung-king, and I-chang (Plate I). We saw the eastern portion of this province only. The western limit lies along the Tibetan plateaus west of the Red Basin of Ssï-ch'uan. On the south the boundary is indefinite, but on the north there is a distinct line between this belt of Paleozoic strata, which are not metamorphosed, and a similarly extensive zone, in which rocks of the same era are metamorphosed.

We entered the province of the middle Yang-tzï at Chön-p'ing-hién, Shen-si, a point on the northern limit (atlas sheet *d* 6); proceeded south to the Yang-tzï at Wu-shan-hién; and thence followed the river to I-chang. The route is given on Plate VII, and details of topography and geology are shown on atlas sheets *d* 6 and *d* 7.

The accompanying columnar section, Fig. 59, gives the sequence of strata for that part of the province which we saw. It is probable that certain relations may differ in other parts of the province, particularly those which characterize the Middle Paleozoic and Permo-Mesozoic. The meager representation of the Silurian, Devonian, and Lower Carboniferous appears to develop to a fuller record further west, along the route followed by von Richthofen,* and his section of Post-Carboniferous rocks is much thicker than anything we saw.

PRE-CAMBRIAN.

HUANG-LING GRANITE-GNEISS.

A granite exposed above Huang-ling-miau on the Yang-tzï is the only Pre-Cambrian formation known in place in the middle Yang-tzï province. The river cuts through a broad anticline, exposing in succession each of the Paleozoic systems, and in the flat dome of the fold finally lays bare the foundation beneath the sediments. The fundamental rock

* China, vol. II, p. 598.

is a massive gneissoid gray granite,* of which the minerals are quartz, plagioclase, biotite, and hornblende, with some epidote, magnetite, etc. The quartz and the feldspar are white or colorless, and, being associated with blackish hornblende and biotite, give a notably speckled, black-and-white aspect. In texture the rock is moderately coarse and evenly grained, the dark minerals appearing usually as larger crystals.

This granite lies beneath Cambro-Ordovician sediments in obvious unconformity. As it was not found associated with other Pre-Cambrian rocks, it is not possible to correlate it with any of the systems of that era which were seen in northern China; but as it is not notably schistose or gneissoid, we regard it as an intrusive of Algonkian, and possibly late Algonkian, age.

Other Pre-Cambrian rocks, which we did not see in place, occur as boulders in the Nan-t'ou Cambrian formation overlying the granite. They consist of hornblende-schists, mica-schists, dioritic and other igneous rocks, and calcareous ferruginous clay slate. Pumpelly also mentions the occurrence of "hornblendic and chloritic schists" with highly inclined schistosity, bordering the granite near the entrance of the Lu-kan gorge.† From this it is inferred that the granite is merely a late intrusive in a metamorphic complex, which is possibly equivalent in stratigraphic position to the T'ai-shan complex of north China.

Pumpelly states that along the western edge of the granitic area the rock is apparently a syenite, containing plagioclase, brown mica, hornblende, magnetite, and a little quartz. Evidently the rock he describes is merely a phase of the Huang-ling granite which is poor in quartz.

UNCONFORMITY AT THE BASE OF THE PALEOZOIC.

The contact of the granite with the overlying sediments was not actually seen, but the character of the basal Cambrian rocks within a few feet of that contact leaves no doubt as to the nature of the division. They are coarse brown sandstones containing conglomerate which increases in prominence as the base is approached. The pebbles in the conglomerate consist almost entirely of small fragments of the gray Huang-ling granite. It is hardly necessary to add that the sandstone exhibits no effects of contact metamorphism, as it would if the granite had been intruded into it.

The time represented by the gap in the stratigraphic sequence is at least that required to erode off the rocks which overlay the granite at the time when it was intruded, and may include several epochs of erosion and deposition, up to the end of the Algonkian.

* In the strict sense this is quartz-diorite, but the word granite is used here in its older and more comprehensive meaning, viz, a rock composed of quartz, feldspar, and accessory minerals.

† Smithsonian Contributions to Knowledge, vol. xv, page 4.

PALEOZOIC.

The Paleozoic era is represented by a thick sequence of sediments of marine origin, beneath which we observed glacial till at one locality. With the exception of the Silurian (Upper) and the Devonian and Lower Carboniferous, all of the periods from Cambrian to Upper Carboniferous are known by fossils. The most prominent features of the Paleozoic are two thick formations of massive limestone, one of them belonging to the Cambro-Ordovician and the other to the Upper Carboniferous period. These are associated with other formations which are largely argillaceous or sandy in composition. Igneous rocks of later age than the basal complex were not seen at any point in the Yang-tzï valley or along its tributary, the Ta-ning-ho, although they are abundant in the valley of the Han, not far to the north.

NAN-T'OU FORMATION.

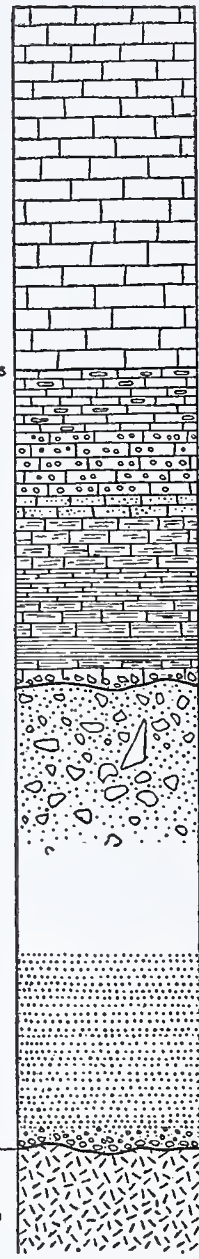
*Basal quartzite and glacial tillite.**—Under this name are grouped the sandy and argillaceous rocks which underlie the first of the great limestones. They are exposed in the gentle slope beneath the cliffs at Nan-t'ou; we can not say whether they occur elsewhere or generally, as we had no other opportunity to follow their horizon, and their character is such as to make it probable that they may be local deposits.

As stated above, the basal strata consist of arkose sandstone and conglomerate, which are purplish-brown in color below, but gradually become white and purely quartzose in the upper strata. Throughout the total thickness of perhaps 150 feet, 45 meters, the texture is coarse and gritty.

The upper member of the formation is distinct from the sandstone, but we did not see the contact and do not know the exact relations.

The next outcrops above the sandstone occur 100 feet, 30 meters, up the slope, and expose about 120 feet, 35 meters, of hard massive boulder-clay or tillite, which is neither fissile nor stratified. It is a greenish gritty clay-rock of hackly fracture, in which lie irregular stones of various sizes and kinds, with their long axes at random angles with the horizontal. The rocks represented are gray granite, brown-rhyolite-porphyry, mica-schist, massive green slate, earthy gray limestones, quartz, and chert. The stones range in size from sand-grains to blocks 50 to 75 centimeters in length, and there is no suggestion of the assortment of the individual sizes. Coarse and fine particles lie indiscriminately mingled and chaotic in their arrangement. The forms of the majority of the stones are subangular, *i. e.*, angles are present, but are smooth and rounded. The flattish surfaces of such slowly weathering rocks as the massive

*Tillite, a term recently proposed for consolidated till.



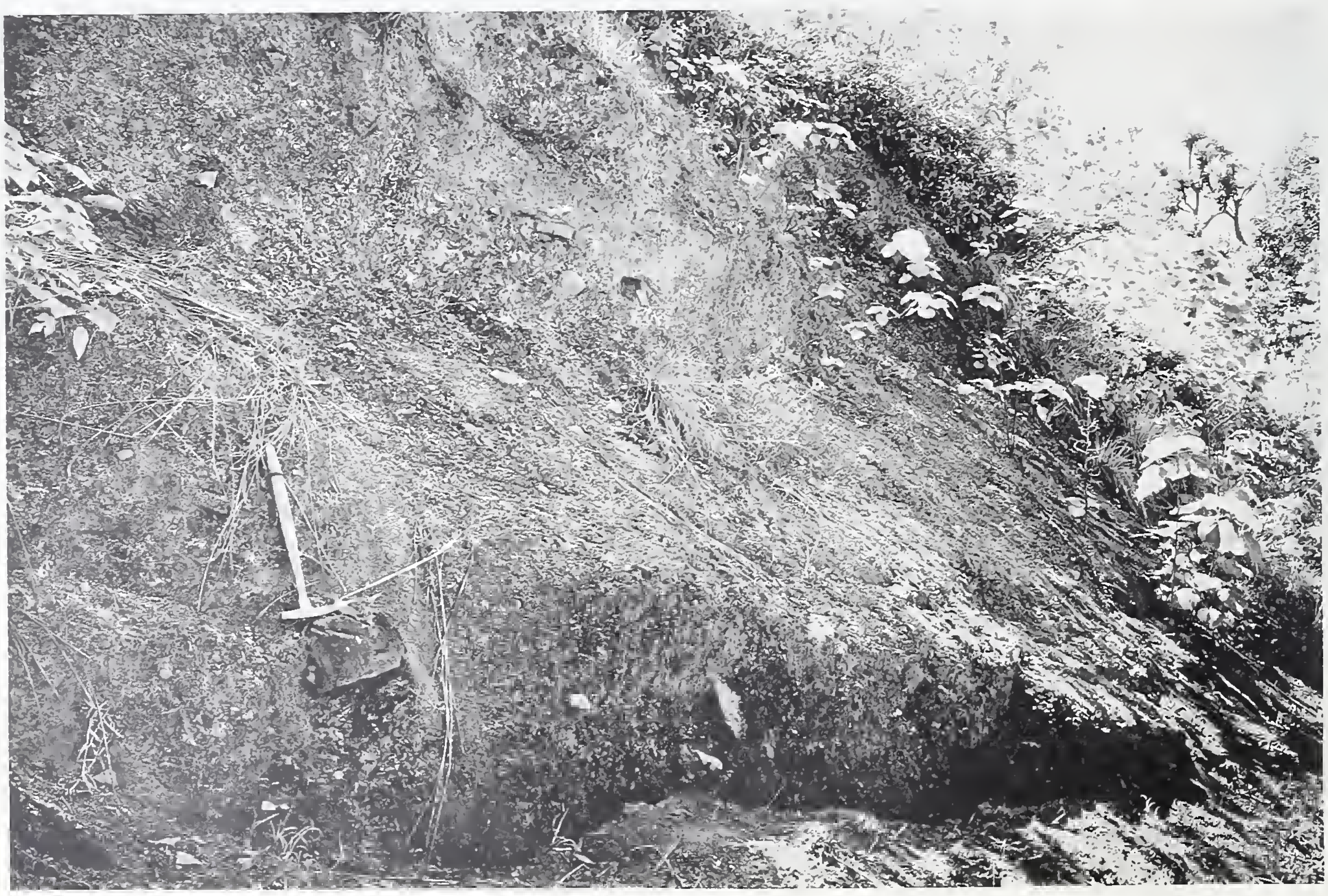
System	Formation	Symbol	Feet.	Meters.	
Cambrian.	Ki-sin-ling limestone.	€Oks	300	90	Massive brown-gray limestone.
			250	75	Gray cherty limestone. Light gray oolitic limestone. White arenaceous limestone. Black argillaceous limestone. Brown calcareous shale. Black slaty limestone and flint. Brown shale. Conglomerate.
	—Unconformity.—				
	Nan-t'ou formation.	€n	120	35	Glacial tillite (green argillite with polished and striated boulders).
			100	30	Obscured by soil.
			150	45	White sandstone. Red sandstone. Conglomerate.
	—Unconformity.—				
Algonkian?	Huang-ling granite.	€h			Granite.
	Total..................		920	275	

FIG. 60.—SECTION OF THE BASAL PALEOZOIC STRATA AT NAN-T'OU, ON THE YANG-TZÏ-KIANG.

siliceous ferruginous limestone are polished and scratched in various directions, and are identical in aspect with pebbles from the Pleistocene boulder clays of North America and Europe. The scratched stones were found in numbers firmly fixed in the green tillite, in such a condition as to show that they had never been disturbed nor subjected to surface abrasion since they were imbedded there in early Paleozoic time.

The promiscuous arrangement of the pebbles, the heterogeneity of the mass and of its lithologic components, the subangular shapes of the

A



B

A. Nan-t'ou on the Yang-tzï. View of cliffs and slope of Cambro-Ordovician strata on south bank of the river, showing the location of the Cambrian glacial deposit with reference to the overlying strata. €nq quartzite at the base of Nan-t'ou formation; €nt layer of glacial till 120 feet thick; €Oks Ki-sin-ling limestone.

B. Bank of Cambrian glacial till, on north side of Yang-tzï-kiang, one mile east of the village of Nan-t'ou. A and B were taken from nearly the same point.

Glaciated boulders and fragment of till from the Nan-t'ou formation; about ¾ the diameters of the original specimens.

stones and especially their striated surfaces, are positive characteristics of glacial till. The evidence of glacial origin is quite as plain as that usually seen in the Pleistocene drift of the United States or Great Britain.

On account of the absence of fossils the age of the Nan-t'ou formation is not accurately known. It lies at the base of the Cambro-Ordovician limestone, from which we obtained Lower and Middle Cambrian fossils within less than 100 miles, 160 kilometers, of Nan-t'ou. Hence it is highly probable that these glacial beds on the Yang-tzï are of early Cambrian age.

Little is known at present regarding the areal distribution of the Nan-t'ou glacial beds. The horizon at which they occur is exposed for many miles both north and south of the Yang-tzï, at the base of the escarpment which is crowned by the Cambro-Ordovician limestone; but the river crosses it at one point only, and we had no other opportunity to see it. At the lower entrance to the Lu-kan gorge Pumpelly examined the base of the limestone system and reported 50 feet, 15 meters, of quartzite overlain by limestones, which contain many layers and lenticular masses of flint.* It is probable, therefore, that the glacial beds do not occur in that locality.

KI-SIN-LING (SINIAN) LIMESTONE.

The lower strata of the Ki-sin-ling consist of thin-bedded limestone with black chert; the greater part is composed of dense limestone, the colors of which range from dark bluish-gray to dull liver-brown. The upper three-fourths are almost devoid of flint and may thus be distinguished from the basal limestones and from the great Wu-shan formation. The individual strata are from 10 centimeters to a meter in thickness, are rarely slabby, and contain only indistinct sections of coiled gastropods, so far as we observed. There are several characters which the formation shares with the Sinian limestone of northeast China and paleontological evidence indicates an approximate correlation of certain beds. The two series were probably contemporaneous and continuous horizontally.

The Nan-t'ou formation is limited above by an uneven surface, upon which lies a thin sheet of conglomerate. The matrix of the conglomerate is a greenish argillaceous limestone and the pebbles are like those in the underlying tillite. The two formations are therefore related by a basal conglomerate, which the till was well calculated to furnish; but it is not probable that there was any considerable interval of time between them.

The conglomerate is at the base of the Ki-sin-ling limestone, and between it and the foot of the great cliffs below Nan-t'ou there rise about 250 feet of rather thin-bedded argillaceous limestones. One of the lowest beds is a black and slaty dolomite, which is distinguished by peculiar

* Smithsonian Contributions to Knowledge, vol. xv, page 6.

discoid nodules of black chert. These nodules are flattened spheroids with a fairly uniform diameter of one or two centimeters. Black chert in thin strata, and less frequently in irregular nodules, is abundant at the top of this limestone member and at other horizons within it. A rock which suggests the middle Sinian limestone of northeast China is a gray half-crystalline oolite, which occurs abundantly in the talus upon these slopes.

The cliffs expose massive strata of gray dolomitic limestone, some layers of which weather to a yellowish hue and others to an ashen white. Strata of similar appearance were noted in the interiors of anticlines at other points along the Yang-tzï and near the headwaters of the Ta-ning-ho.

The thickness of the massive portion of the Ki-sin-ling limestone in the Nan-t'ou section is estimated at something more than 4,000 feet, 1,200 meters, and for the lower slaty layers 200 to 300 feet, 60 to 90 meters, more should be added. Our search for fossils was without success, though we continued it during two hours on the lower cliffs and talus slopes near Nan-t'ou.

On top of the characteristic Ki-sin-ling limestone, as it is exposed on the upper reaches of the Ta-ning-ho, there is an alternation of soft green calcareous shales with thin strata and nodules of limestones of gray and white colors about 200 feet, 60 meters, thick. These are separated from the overlying Sin-t'an formation by a hard light-colored limestone and thin stratum of dense black chert, lydite. In the shales and thin gray limestones there are abundant fossils. Dr. Stuart Weller has studied them and finds that they correspond closely with those of the Middle Ordovician or Trenton horizon of the eastern United States. In the more massive limestone directly beneath the shales there are also numerous well-preserved casts of *Orthoceras*.

These fossils were first found at a rocky narrows on the Ta-ning-ho, about 1.5 miles, 2 kilometers, up the river from Sü-kia-pa (atlas sheet *d* 6). They occur in seams of thin gray limestone interbedded with green shales, which, in this locality, form a transition zone above the massive limestone and are 100 to 200 feet, 30 to 60 meters, thick. In these layers trilobites and brachiopods, with a few other forms, are exceedingly abundant. The collection from this station comprises the following recognizable forms:

Cornulites sp.
Lingula (?) sp.
Strophomena sp.
Plectorthis willisi Weller
Dalmanella testudinaria Dalman
Clitambonites chinensis Weller
Gastropod indet.
Vaginoceras sp.
Ampyx sp. (cf. *Ampyx costatus* Boeck)
Asaphus lævis Weller
Asaphus sp.
Isotelus (?) sp.
Megalaspis minor Weller
Prœtus sp.

While following this horizon southeastward along the strike of the syncline, we found fossils again abundant near the mouth of the ravine immediately northeast of Sü-kia-pa. Here, as before, the fossils occurred in gray limestone associated with green shales, and it is evident that the horizon is equivalent to the one just described. It is, however, a matter of surprise that the two lots collected have so few specimens in common. The list from this locality comprises:

Strophomena sp.	*Bathyurus* sp.
Triplecia poloi Martelli	*Asaphus* sp. (cf. *Asaphus expansus* Dalman)
Orthis calligramma Dalman	*Asaphus asiaticus* Weller
Dalmanella testudinaria Dalman	*Asaphus chinensis* Weller
Dalmanella subæquata Conrad	*Asaphus* sp. (several indet.)
Plectorthis willisi Weller	*Isotelus* sp. (hypostoma)
Clitambonites chinensis Weller	*Isotelus* sp. (pygidium)
Hemipronites tenuistriata Weller	*Illænus* (?) *bronteoides* Weller
Gastropod indet.	*Prætus* (?) sp.
Cyrtodonta (?) sp.	*Calymene* (?) sp.
Ampyx chinensis Weller	*Pterygometopus* (?) sp.

South of Sü-kia-pa, where the river passes through a box canyon, this fossiliferous horizon dips beneath higher Paleozoic rocks, and does not reappear until the Yang-tzï river is reached. In the lower gorges of the great river the formation is exposed in several places, but our journey was too rapid to permit of any further search for fossils.

Just above Ta-miau-ssï, Ssï-ch'uan, atlas sheet *d* 6, the lower thin-bedded portion of the Ki-sin-ling formation reappears, probably for the first time north of the Yang-tzï gorges. The rocks consist of an alternation of brown, gray, and black slaty limestones among which are black oolites not unlike the Ch'ang-hia oolitic limestone of Shan-tung and the corresponding Middle Cambrian oolites of northern Shan-si. No fossils were found in this series, but inference based on the structure and the occurrence of the black oolite indicates that the beds are Cambrian.

On the northern slope of the divide between Ssï-ch'uan and Shen-si, and south of Chön-p'ing-hién, the Ki-sin-ling limestone is exposed in two large anticlines bounded by synclines in the Sin-t'an shales. In this locality the Middle Ordovician shaly horizon, which was observed near Sü-kia-pa and described above, appears to be represented by continuous limestones, and fossils of that age were not found. The Nan-kiang, along the canyon of which we ascended toward the Ki-sin-ling pass, did not appear to have cut sufficiently deep into either anticline to expose the base of the system, but in the shingle of the river a mile above Chön-p'ing-hién, we found pebbles of gray-green oolitic limestone, pisolitic and

conglomeratic limestone, and slaty black limestone, all resembling in a measure, certain phases of the lower Sinian rocks in Shan-tung. Upon some of the limestone pebbles occur trilobite spines and certain poorly preserved, yet recognizable, shells; better specimens were found within the rock. Trilobites are comparatively rare, the most abundant fossils being certain small ostracods, of which no less than six species have been found. The fossils are principally of the Middle Cambrian, yet in most respects they are unlike those of equivalent age in Shan-tung and Shan-si. The common forms are a brachiopod, *Obolus shansiensis*, found also in central Shan-si; and another, *Dicellomus parvus*, which occurs in the upper green shale of the Kiu-lung formation near Yen-chuang, Shan-tung. *Obolella asiatica* occurs in the Man-t'o, Lower Cambrian, formation in Shan-tung.

The entire list of species from near Chön-p'ing-hién is as follows:

Dicellomus parvus Walcott	*Bradoria bergeroni* Walcott
Obolella asiatica Walcott	*Bradoria enyo* Walcott
Obolus shansiensis Walcott	*Bradoria eris* Walcott
Orthotheca doris Walcott	*Bradoria fragilis* Walcott
Microdiscus orientalis Walcott	*Bradoria sterope* Walcott
	Bradoria woodi Walcott

The exact position of the fossil-bearing strata is not known, but there can be little doubt that they occur in the lower part, though probably not at the base of the Ki-sin-ling limestone.

Northward from Chön-p'ing-hién the discrimination of formations becomes increasingly difficult, not only on account of the complex folding, which obscures structural relations, but particularly because of regional metamorphism which, in the basin of the Han, has converted the more susceptible sediments into schists and has greatly altered even the massive limestones. These rocks are described separately in a following section of this report.

The age of the highest transition beds is fixed as Ordovician by the fossils found at Sü-kia-pa, and the Chön-p'ing fossils show that at least Middle Cambrian is included; Lower Cambrian strata probably occur at the base as is indicated by *Obolella asiatica*.

The upper limit of the Ki-sin-ling limestone is not well determined by our observations. There is conformity of bedding between it and the overlying Sin-t'an formation, and about 200 feet of transition strata carrying Middle Ordovician fossils intervene. They may ultimately be separated as a distinct formation, but are here considered as continuous with, but above the Ki-sin-ling in this region.

SIN-T'AN SHALE.

The Sin-t'an formation is prevailingly composed of olive-green argillite or massive shale, which is rather soft and frequently sandy, but not fissile. The sandy material occurs chiefly in the form of grains ranging up to the size of wheat, which are scattered rather than gathered in distinct layers. The lowest strata in the Sü-kia-pa region are black and brown clay-shales having a thickness of less than 100 feet. A typical massive green argillite follows, completing the formation with only slight variations. Near T'an-mu-shu-p'ing the uppermost layers are partly reddish mudstones. Again, 2 miles, 3.5 kilometers, above Ta-ning-hién, the upper horizon of the green argillites contains local thin strata of olive-green quartzite and earthy limestone. Just below Ta-miau-ssï the Sin-t'an formation contains not only green, but brown and gray argillites with thin coaly layers. This phase of the formation reappears in the main divide at the Ki-sin-ling and again in the vicinity of Chön-p'ing-hién. About halfway between the last two points, near Wa-tzï-p'ing, coaly layers are prominent, but no reliable report of the existence of workable coal in that vicinity was obtained. North of Chön-p'ing-hién metamorphism renders the formation more and more schistose and difficult to recognize. Besides the occurrences on the Ta-ning-ho and northward, the Sin-t'an appears along the Yang-tzï in the magnificent Wu-shan gorge, the I-chang gorge, and at Sin-t'an. The name of the last place has been adopted as a designation for the formation.

The thickness of the Sin-t'an formation, as determined from the sections obtained on the Ta-ning-ho, is about 1,800 feet, 500 meters.

In the transition with the underlying Ki-sin-ling (Sinian) limestone, the shale lies directly upon an even and unweathered surface of limestone as if in conformable relation. Where the limestone lies overturned upon the Sin-t'an, on the south side of the Ki-sin-ling, the transition between the formations was noted particularly, the layers of shale including seams of limestone which become more abundant and pass quickly into massive dark limestone with local shaly partings. Wherever observed, the contact with the overlying Wu-shan (Carboniferous) limestone presented an appearance of conformable bedding. Both upper and lower limits of the Sin-t'an are, therefore, regarded as conformable contacts.

The green and variegated shales of the Sin-t'an have as yet yielded no fossils, but a small assemblage was obtained from a gray limestone which might be considered as occurring in the top of the Sin-t'an or at the base of the Wu-shan, in an exposure at the upper end of the chasm, immediately north of Tung-kuan-k'óu and south of Ta-miau-ssï (atlas sheet *d* 6). The fossils occur in granular greenish-gray siliceous limestone,

through which are scattered abundant pink crystals of calcite, and which is interbedded with thin layers of greenish shale.

From this material Dr. Girty has identified the following:

Fistulipora willisiana Girty	*Fenestella* (?) sp.	*Rhynchonella* (?) sp.
Fistulipora sp.	*Dalmanella* (?) sp.	*Prœtus* (?) sp.
Leioclema sp.	*Schuchertella* (?) sp.	Fish plate (?)
Tæniodictya (?) sp.	*Spirifer* (?) sp.	Crinoidal fragments

It will be observed that, with the exception of the genus *Fistulipora*, none of the forms in this list occur in any of the other lots collected from the base of the Wu-shan limestone.

The evidence furnished by this fauna is not conclusive. The bryozoans are considered by Ulrich and Bassler as of Lower Carboniferous (Mississippian) age. The associated forms, however, are not entirely consonant and suggest to Girty an earlier period—Devonian or possibly Silurian. It is evident that the association is an unfamiliar one, which indicates an earlier appearance of the bryozoans or a later range of the brachiopods. In the Wu-shan limestone at Tung-kuan-k'óu, about 1,200 feet, 360 meters, above this horizon and in the immediate vicinity, Upper Carboniferous (Pennsylvanian) forms were collected. Furthermore, fossils obtained on the Ta-ning-ho, from the basal layers of the Wu-shan, are also of Upper Carboniferous age, and it is therefore probable that no part of the great limestone can be assigned to the Lower Carboniferous. We thus have no more than a few feet of shale between a definite Upper Carboniferous horizon and a doubtful one, which is either Lower Carboniferous or earlier. We do not think it can be much earlier and therefore assign it, and with it the passage from Sin-t'an shale to Wu-shan limestone, to the Lower Carboniferous. As the middle Ordovician fauna collected at Sü-kia-pa is close to the transition zone from the Ki-sin-ling limestone to the Sin-t'an shale, that is, near the base of the shale, it is evident that the Sin-t'an formation, 1,800 feet, 540 meters, thick, represents Silurian and Devonian time in this region. What part of it may be Silurian or Devonian, and what intervals may be represented by little or no sediment, we do not know.

WU-SHAN LIMESTONES.

Across the Yang-tzï from the town of Wu-shan-hién rise the smooth dip slopes of a hard limestone, which is completely cut through by the Yang-tzï in the magnificent Wu-shan gorge. The same great limestone is exposed in successive folds in most of the other gorges, both on the Yang-tzï and the Ta-ning-ho. In a well-determined section it measures 3,400 feet, 1,050 meters, without the lower part; the total thickness is estimated at about 4,000 feet, 1,200 meters.

Broadly speaking, the entire formation is composed of dark gray or blackish limestone, with a few seams of shale and even anthracite coal in occasional local layers. In detail the various horizons show some individuality worthy of note.

The lower part of the formation, from the headwaters of the Ta-ning-ho to Wu-shan, contains abundant nodules of black flint. So persistent and peculiar is this feature that it may be relied on as a means of identifying the horizon. A local variation is observed in the gorge just above Ta-ning-hién, where soft green shales and thin limestones are substituted for 200 feet, 60 meters, of the massive limestone at a horizon about 800 feet, 250 meters, above the base of the formation. Along the Yang-tzï, below K'ui-chóu, the succession is similar, and a thin layer of quartzite is interbedded with the limestone near the base of the formation.

Anthracite coal occurs on the Ta-ning-ho, in the limestone at Tung-kuan-k'óu about 1,200 feet, 350 meters, and at T'an-mu-shu-p'ing about 2,000 feet, 600 meters, above the base. At Tung-kuan-k'óu the occurrence is very local; at T'an-mu-shu-p'ing there is a bed apparently about a meter thick and mined throughout the syncline on both sides of the river. It does not occur at the appropriate horizon elsewhere. The limestones are partly shaly at the coal-bearing horizon; yet the massive limestones predominate and the coal is sometimes embedded in them directly.

We have stated on a preceding page that the Wu-shan limestone lies upon the Sin-t'an shale in apparent conformity. Throughout the greater part of this limestone organic remains are either absent or vestigial, but occasionally they appear in considerable numbers. We have collections from three different horizons, all of them secured in the upper canyons of the Ta-ning-ho. According to Girty they are related to the Upper Carboniferous (Pennsylvanian) faunas of the United States, but the facies is distinctly different from that of the typical Pennsylvanian. The resemblance is rather with the Pennsylvanian faunas of western North America, and still more with the faunas of the Salt Range of India and the Gschelstufe of Russia. Some of the other collections from this formation, as well as some of those obtained at other points, suggest the typical Pennsylvanian much more distinctly than the three which follow. They mostly comprise but a few species in a poor state of preservation, and the resemblance may fairly be said to be, in part at least, due not so much to the presence of types peculiarly Pennsylvanian as to the absence of such as are characteristic of other faunas and the presence of widely distributed ones which are common to many faunas, the Pennsylvanian among them. It might reasonably be expected in some cases that more complete collections would considerably reduce the relationship at present appearing.

About 2 miles, 3 kilometers, north of Ta-ning-hién, we found in the lowest layers of the Wu-shan limestone a varied, although poorly preserved fauna. The rock is a dark gray limestone which is locally rich in nodules of flint. Being more resistant to weathering, the fossils stand out in relief on the exterior surfaces. In most cases it has been impracticable to identify the species positively. The list from this locality included:

Schwagerina sp.	*Productus* (?) sp.
Lonsdaleia chinensis Girty	*Spirifer blackwelderi* Girty
Michelinia favositoides Girty	*Spirifer* sp.
Syringopora sp.	*Pelecypod* indet.
Geinitzella chinensis Girty	*Euomphalus* sp.
Fistulipora waageniana Girty	*Phillipsia* sp.
Orthotichia (?) sp.	Crinoidal fragments

Another small collection was taken also from the basal layers of the Wu-shan formation, 1 mile above the junction of the two main tributaries of the Ta-ning river north of Miau-ïr-t'an. It has only one species in common with the last, but a larger collection would doubtless show closer resemblance between the two:

Carnegia bassleri Girty	*Martinia* (?) sp.
Derbya sp.	*Hemiptychina* (?) (cf. *Hemiptychina orientalis*)
Productus (?) sp.	*Notothyris willisiana* Girty

Near the salt wells of Yen-ch'ang, on the Ta-ning-ho, another fossiliferous horizon was discovered, about 800 to 1,000 feet, 240 to 300 meters, above the base of the formation. This is exposed in the axis of an anticline which is cut through by the canyon a little more than a mile east of the village. The only fossils found here are numerous bryozoans, embossed upon the weathered surfaces of the dark gray limestone:

Geinitzella chinensis Girty   *Batostomella meekana* Girty

In the limestone canyon below Ta-ning-hién, a few poorly preserved fossils were found in brownish cherty layers. The exact position of this horizon in the section was not determined, but it is probably not far from the middle of the Wu-shan formation. These fragments comprise:

Schizodus sp. (cf. *Schizodus curtus*)   *Gastropod* indet.

At Tung-kuan-k'ou, about 1 mile, 1.5 kilometers, south of the point where fossils were found in the top of the Sin-t'an, a very few fossils were collected in débris from a thin seam of black shale which was associated with a layer of anthracite coal. The rocks lie in the middle of a vertical syncline and are believed to occur about 1,200 feet, 350 meters, above the base of the Wu-shan limestone:

Chonetes sp.   *Ambocœlia* sp. (cf. *Ambocœlia planiconvexa*)   *Cliothyris* (?) sp.

The upper half of the Wu-shan formation consists of massive dark limestone, almost without interruption; fossils are apparently rare.

PERMO-MESOZOIC.

PRE-K'UI-CHÓU UNCONFORMITY.

The relation between the Wu-shan limestone and the K'ui-chóu series was not determined by close observation of the contact in the field. The upper surface of the limestone may be eroded on a plane very nearly parallel to the stratification, but we saw no evidence of such an effect. The immediately overlying strata, consisting of several hundred feet of red shale and a heavy bed of massive bluff-making limestone, were the same in the different sections seen on the Ta-ning-ho and near K'ui-chóu on the Yang-tzï. The presence of a hiatus is suggested, however, by the marked difference in character between the two formations and by the presence of coarse conglomerates which, at I-chang, lie near the base of the supposed K'ui-chóu.* We also found loose pieces of conglomerate in the river gravel near the base of the K'ui-chóu below Ta-ning-hién, consisting of pieces of the Wu-shan limestone and flints embedded in a hard sandstone. They may represent a later formation, but the conglomerate is hard and has undergone some mechanical deformation; hence it is probably not younger than the period of post-K'ui-chóu folding. Von Richthofen describes an unconformity with marked discordance of dip at this horizon in Ssï-ch'uan, and the unconformity, without marked discordance, may exist in the middle Yang-tzï.

K'UI-CHÓU SERIES.

In several synclines in the Carboniferous limestone we observed incomplete sections of a series which consists mainly of red shales and red sandstones with occasional gray limestones. The lower members are deep red, but at higher horizons brown, gray, and even black sediments occur. Where this series occurs on the Yang-tzï at K'ui-chóu, Hu-peï, it was examined by Pumpelly† and von Richthofen on account of the coal which it contains. It is also referred to by Blakiston.‡

In the Ta-ning-ho sections the lowest member consists of deep red sandy shales about 400 feet, 120 meters, thick, with which thin seams of gray and bright green shales are interbedded at intervals of 1 to 3 feet, .3 to 1 meter. Calcareous gray shales become somewhat prominent at the top of this member, and are succeeded conformably by a firm semicrystalline limestone of clear gray color, which occurs in beds 1 to 3 feet, .3 to 1 meter, thick, is more than 100 feet, 30 meters, in thickness, and is sufficiently resistant to make prominent bluffs along the river. Softer strata occur above the bluff-forming limestone, and consist of gray and reddish shales with red sandstones and impure limestones in thin strata. The details of the sequence are not known. Along the Ta-ning-ho the red

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* Smithsonian Contributions, vol. xv, Geological Researches in China, Mongolia, and Japan, p. 6.
†*Ibid.* ‡ Five months on the Yang-Tsze. T. W. Blakiston, 1862, page 133.

series seems to be devoid of coal, which may lie higher in the system than any strata remaining in those synclines.

Although we were not able to make a detailed examination of the beds at K'ui-chóu on the Yang-tzï, the succession there seemed to be similar in the large to that just described, with the exception that Pumpelly reports, in place of the basal red shale, a fine-grained micaceous sandstone grading upward into calcareous sandstone. The gray limestone there is slightly thicker. Nearly 5 miles, 8 kilometers, below Pa-tung-hién it contains a workable coal-seam near its base, and 2 miles, 3 kilometers, above K'ui-chóu six thin seams of coal in the same limestone are being mined for the manufacture of briquets.

East of the mountains of Carboniferous limestone at I-chang, there is apparently a recurrence of the K'ui-chóu formation. As the massive Wu-shan limestone declines beneath the river at a gentle angle, it is followed by coarse conglomerates, sandstone, and sandy shale, which are locally reddish. We had no opportunity of examining the rocks, but the description of them given by Pumpelly is here quoted as significant:*

> Near the city of I-chang, at the eastern mouth of the gorge, the limestone strata, trending here N. E., and dipping about 8° to the S. E., are covered by apparently conformable beds of fine-grained, gray sandstone, which, toward the top, soon merges into a coarse conglomerate. The change is very marked, the upper portion of the sandstone containing rounded fragments of chert near the contact, and the lower part of the conglomerate having lenticular deposits of sandstone. This transition appears to mark some important change that took place during the formation of these deposits, and the fact that, in transverse section, they border the river for 12 miles and have a great thickness, would seem to indicate that this change was not confined to the immediate neighborhood. This conglomerate is followed by a red sandstone, which above Itu dips easterly, and below that place westerly. From here eastward the country on both sides of the river is flat, the rocks being covered for the most part by alluvial deposits.

As the K'ui-chóu series is the highest formation in the sequence exposed in the lower gorges of the Yang-tzï, and has therefore been partly removed by erosion, we can not estimate the total thickness of the formation. The sections we saw are probably less than 1,000 feet thick.

Fossils were found in the gray semicrystalline limestone, about 400 feet, 120 meters, above the base of the formation just above the red sandy shales, near San-shï-li-p'u on the Ta-ning-ho. One brachiopod (a terebratuloid) is abundant in certain layers of this limestone, but unfortunately it can not be identified with certainty. In addition to the species in the following list, the microscope shows here and there shells of foraminifera resembling those of the family Textulariidæ:

Dielasma sp. (cf. *Dielasma elongatum*)	*Pelecypod* indet.
Aviculipecten (?) *richthofeni* Girty	Crinoidal fragments

* Smithsonian Contributions, vol. xv, Geological Researches in China, Mongolia, and Japan, p. 7.

Girty regards this fauna as Paleozoic rather than Mesozoic. He says:*

The greatest doubt surrounds the highest of the supposed Carboniferous or Permian faunas, that which was found in a gray limestone interstratified with the red beds 7 miles, 11 kilometers, south of Ta-ning-hién. From this horizon our collection affords only round crinoid stems. *Dielasma* (?), cf. *D. elongatum*, *Aviculipecten* (?) *Richthofeni n. sp.*, and indeterminable fragments of pelecypods.

The little pectinoid described as *Aviculipecten ? Richthofeni* is of a type which is common in the Paleozoic and doubtless in the Mesozoic as well. The cardinal structures and therefore the generic position can not be ascertained from our material. The Terebratuloid cited as *Dielasma ?* cf. *D. elongatum* has two large dental plates, but the structures of the dorsal valve, which are usually more difficult to ascertain, have not been satisfactorily determined. I believe that it is not definitely known to what extent Mesozoic Terebratuloids develop plates in the ventral valve, but it appears to be rather a peculiarity of Paleozoic shells. Upon this point Waagen says, speaking of Hemiptychina: "The genus is distinguished very characteristically from the greater number of Paleozoic *Terebratulæ* by the absence of dental plates in the ventral valve. In this respect it approaches more closely the Mesozoic forms, in which dental plates are nearly always absent." (India Geol. Surv. Mem., Palæontologia Indica, Salt Range Fossils, Vol. I, p. 361.)

It would appear from this that this type of structure is more common in the Paleozoic, though not entirely confined to faunas of that period.

The evidence upon which the horizon in question is referred to the Paleozoic consists of the septiferous Terebratuloid, the round Crinoid stems, and the general Paleozoic complexion of the fauna. It is inconclusive and may not stand against any facts which strongly point to a Mesozoic age. For this reason my assignment to the Carboniferous is provisional only, and should the necessity arise of changing to a younger period, the readjustment would entail no serious conflict of evidence.

The age of the coal-bearing strata at K'ui-chóu has been determined by previous observers as Triassic or early Jurassic. In 1866 Pumpelly brought thence a small collection of fossil plants,† which were submitted by him to Dr. J. S. Newberry, who concluded that the fossils were most closely related to those of the late Triassic coal-measures of Virginia and North Carolina, and to certain Liassic forms of Europe. Collections made by von Richthofen at K'ui-chóu‡ and also others made by him and later by Lóczy at Kuan-yüan-hién§ in the province of Ssï-ch'uan, were assigned by Professor Schenk to the Jurassic.

White, after critical consideration of all the evidence thus far reported, confirms the original opinion that the K'ui-chóu plants are related to those of the European Rhetic more nearly than to any other known flora. His report follows.

* Research in China, vol. III. Paleontology. Report on Carboniferous Fossils, by George H. Girty.

† Smithsonian Contributions to Knowledge, vol. XV, Geological Researches in China, Mongolia, and Japan, pp. 119–120.

‡ China, vol. IV, p. 266.

§ Von Richthofen, China, vol. IV, p. 265, and Lóczy: Wissensch. Ergeb. der Reise des Grafen Béla Széchenyi in Ostasien (German edition) III, p. 324.

AGE OF THE PLANT BEDS IN THE K'UI-CHÓU BASIN.

By David White.

The question of the determination, from the paleobotanical standpoint, of the age of the coals in the K'ui-chóu* basin rests solely on the scant fossil plant material brought back by Pumpelly and von Richthofen and studies by Newberry and Schenk. The combined flora embraces but ten species, of which but two, Nos. 7 and 8 of the following list, were reported by Newberry, No. 7 being also included among the nine species identified by Schenk.

1. *Angiopteridium richthofeni* (*Angiopteris richthofeni* Schenk)
2. *Cladophlebis petruschinensis* (*Asplenium petruschinense* Heer)
3. *Rhabdocarpos densus* Schenk
4. *Nilsonia compta* (Phill.) Goepp
5. *Pterophyllum nathorsti* Schenk
6. *Pterophyllum contiguum* Schenk
7. *Podozamites lanceolatus* (L. & H.) Braun
8. *Podozamites emmonsi* Newberry
9. *Czekanowskia rigida* Heer
10. *Araucaria prodromus* Schenk

Meager as was the collection in his hands, Newberry regarded the beds as Triassic chiefly on the identity of the *Podozamites emmonsi* with the plant from North Carolina. Schenk, on the other hand, judged the plant-bearing terranes to be at furthest not older than Rhetic, and as most probably belonging to the lower Jurassic. Plainly the former was strongly influenced† by his recent acquaintance with the older Mesozoic flora as then known on the American continent, while the latter was naturally inclined to make close comparison with the flora from eastern Siberia, not long before described by Heer as Jurassic.

An attempt to confirm or revise either of these conclusions in the light of the distributional knowledge gained in the last score of years is inevitably rendered more difficult and less satisfactory in the end by inability to consult the original collections. At best and under the most favorable circumstances, the collections themselves are far too limited in species and too deficient in forms restricted in vertical range to decide with refinement as well as certainty the important question presented by the stratigraphy and the fossil invertebrates. At present two of the species, *Rhabdocarpos densus* and *Araucaria prodromus*, are essentially of no stratigraphic value. None of Schenk's K'ui-chóu species is sufficiently illustrated.

If we examine the discussions and figures published by Newberry and Schenk, and take into careful consideration the distribution observed for

* K'ui-chóu is commonly spelled Kwei-chou in earlier reports.
† See Amer. Journ. Sci., vol. XXVI, 1883, p. 126.

each species, we find, omitting all details, that *Angiopteridium richthofeni* does not seem to have been found elsewhere. Its well-marked fertile fronds belong to a type represented by *Angiopteridium münsteri*, characteristic of the Rhetic in Europe. *Cladophlebis petruschinensis* is illustrated by a poor fragment regarded as identical with Heer's plant from beds supposed to be Jurassic in eastern Siberia. Several eminent paleobotanists synonymically refer this species to *Cladophlebis dentata* (Brongn.) Nath., common and widely distributed in the Jurassic. But specimens which, to judge by the figures, are as near Schenk's plant as are Heer's types were figured by Schmalhausen from beds now generally admitted to be Permian on the lower Tunguska and in Petchora. Much doubt existed in Schenk's mind as to the nature of his *Rhabdocarpos densus*, which he regarded as either an inflorescence or form of fructification. A thorough study of this fossil, to which the name *Rhabdocarpos* should not be applied, and which is probably Cycadean, may result in interesting and important paleobotanical information. As remarked previously, the species is not recorded from any other locality. Schenk considered his *Nilsonia* as too near *Nilsonia compta* for separation; but, whatever the degree of doubt as to the specific identity, it appears to be closely related to that plant. The presence of *Nilsonia* is significant in that it points to Jurassic or Upper Triassic age, most of its species being confined to the Rhetic, Lias, and Oolite.

Both *Pterophyllum nathorsti* and *Pterophyllum contiguum* are reported from beds regarded as Oolite in age in Oregon, *Pterophyllum contiguum* being found also in the Rhetic of Hongäy in Tonkin. The genera *Pterophyllum* and *Podozamites* both had a long existence, the former dating from the latest Carboniferous, while the latter extends from the Triassic to the Middle Cretaceous. *Podozamites emmonsi*, said by Newberry to be abundant in the Pumpelly collection, is typical in the Carolinian Triassic, while *Podozamites lanceolatus* is common in the Rhetic and Oolite. Consultation of the literature shows nearly the same range for *Czekanowskia rigida*, to which Schenk referred one of Richthofen's specimens, though, if Schmalhausen's identification is valid, the species dates back to the Permian. This seems somewhat improbable. *Araucaria prodromus*, the last of Schenk's species, is not reported elsewhere, and from both his discussion and small illustration we must conclude that it is very ambiguous and of little importance.

From the above very brief summary it appears that the direct evidence offered by the distribution of the individual species of this very insufficient flora points to a Mesozoic age, probably not older than Rhetic nor younger than Oolite. The testimony of *Angiopteridium richthofeni*

and *Podozamites emmonsi* is, I believe, more or less distinctly for a Rhetic correlation; and this reference seems to find support, not only in the general affinity of the flora to that of the Rhetic in eastern Asia and Europe, but also in the absence of species distinctly characteristic of the Jurassic.

It may well be urged that a more satisfactory collection containing additional species might bring to hand forms indicating an earlier or a later age. The possibility, which most paleobotanists will admit, that the discovery of additional species might reveal the presence of types characteristic of the Lower Gondwanas, such as would indicate a reference of the beds to the Permian, in accordance with the fossil mollusks and the stratigraphy, is the chief cause for this discussion. For if it is permissible even tentatively to regard the flora as falling within the upper limits of the Paleozoic, it then will not be necessary to conclude that the K'ui-chóu series transgresses from the Permian into the Mesozoic.

Even in the small amount of material available the representatives of *Nilsonia*, *Podozamites*, and *Angiopteridium* are in themselves sufficient to preclude a consideration of the flora as possibly belonging to that of any horizon of the latest Carboniferous or Permian in Europe or North America. The alternative that they may be fragments of the Lower (Paleozoic) Gondwana flora, near whose province the K'ui-chóu basin lies, would at first hand seem to be favored by the slightly Mesozoic aspect of the other Gondwana floras and the appearance of Secondary types in the flora of the Middle Gondwana.

Viewed from the Paleozoic Gondwana point the evidence is largely, but far from wholly, negative. Not only have none of the types characteristic of the Lower Gondwanas yet been found in the K'ui-chóu basin, but the species from the latter include nothing, with the possible though doubtful exception of *Cladophlebis petruschinensis*, that, so far as I am aware, has yet been found at any point in the Lower Gondwanas. Fructifications of the group represented by *Angiopteridium richthofeni* are not yet known below the upper Trias; nor is the genus *Nilsonia* of an earlier date. *Podozamites lanceolatus* occurs in the Upper Gondwanas at Jabalpur and in the Trias at Ipswich in Queensland; but the presence of the genus *Podozamites* itself at K'ui-chóu argues against a Permian age. Furthermore, it is important to note that Cycads appear to dominate in the K'ui-chóu flora, while in the Paleozoic Gondwanas they are very rare or almost wanting and are practically restricted to the genus *Pterophyllum*. Remains of Cycads are perhaps as infrequent in the Permian rocks of the Gondwana province as in the contemporaneous strata of Europe. The same is true of *Cladophlebis*. Regarding *Czekanowskia rigida*, whose distribution is Mesozoic, it must be said that the identification by both Schenk and Schmalhausen is questionable.

On the whole, the paleobotanical data in hand from the K'ui-chóu basin can not at present be regarded as offering any significant evidence of Paleozoic age, either through direct connection with the Northern Permian flora, or indirectly through a relationship with the Paleozoic Gondwana floras. On the contrary, the connection with the Mesozoic, including the Upper Gondwana, plant life is direct and evident, though possibly less intimate than with that of the older Mesozoic of Europe and eastern Asia. We are therefore, I believe, compelled to regard the K'ui-chóu plant-bearing beds as Mesozoic; and, since the known species appear to be most closely bound to the Rhetic flora, as probably Upper Triassic. At the present moment the comparative distributional facts tend only to confirm the opinion long ago entertained by Newberry. The paleobotanical materials, though unfortunately meager in amount and deficient in species, demand that, for the present at least, the phytiferous portion of the K'ui-chóu series be considered as Triassic if not actually Rhetic.

Commenting on the apparent contradiction of evidence brought out in the reports of Girty and White, it is desirable to emphasize the fact that the molluscan fauna of Permian aspect is stratigraphically lower than the flora of Triassic character. Occurring at the base of a massive marine limestone over 100 feet, 30 meters, thick, the former is separated from the higher coal-bearing phytiferous beds, not only by most of the limestone, but also by several hundred feet of sandstone and shale. We do not know exactly where the plants were collected, and have no detailed section of the K'ui-chóu series in the type locality. We feel justified, therefore, in accepting the opinion of Girty, and also that of White, and calling the K'ui-chóu series Permo-Mesozoic.

CHAPTER XIII.

STRUCTURAL GEOLOGY OF THE MIDDLE YANG-TZÏ PROVINCE.

By Bailey Willis.

DEFINITION OF THE PROVINCE.

The geologic province of the Yang-tzï river, as it is here defined, is a region within which strata of Paleozoic and Mesozoic age are folded in apparent conformity, without notable metamorphism; and which presents structures of the Appalachian type. Its limits are only partially known; the eastern boundary, at which the strata sink beneath the alluvium of the Great Plain of China, crosses the Yang-tzï at I-chang. The northern boundary is a transition zone between the Yang-tzï province and the metamorphic province of the Han watershed, which we crossed at Chön-p'ing-hién, whence it extends east by south past Chu-shan-hién, Hu-peï, and west by north, south of Han-chung-fu, Shen-si. Toward the west it extends beneath the red beds of the basin of Ssï-ch'uan and is continued in the ranges which trend north and south along the eastern borders of Tibet. Its limits south of the Yang-tzï are not determined.

Referring the reader to the preceding chapter by Blackwelder, for discussion of our observations on stratigraphy I take up the description of structure at I-chang, and follow the sequence of folds up the Yang-tzï to Wu-shan-hién and thence up the Ta-ning-ho, and northward across the Ki-sin-ling range to Chön-p'ing-hién. At the latter place the discussion joins that of the metamorphic rocks of the Han watershed. The length of the section across the strike is about 50 miles, 80 kilometers, on the Yang-tzï and 46½ miles, 75 kilometers, up the Ta-ning-ho and beyond to Chön-p'ing-hién.

YANG-TZÏ SECTION: I-CHANG TO WU-SHAN-HIÉN.

DETAILS OF THE YANG-TZÏ SECTION.

Northwest of I-chang the mountains rise from the plain in a long slope to a range of striking peaks. The slope is the bared dip plane of the Wu-shan (Carboniferous) limestone; the crest is the upturned edge of the limestone. The dip is 10° to 15° southeast. In contrast to the dead level plain which stretches far to the eastward, this mountain front, which is probably 4,000 feet, 1,200 meters, or more in height, is surprisingly

imposing, and it has been described in terms which exaggerate the steepness of its southeastward slope. Von Richthofen was thereby led to consider it a fault-scarp,* but there is no fault such as he inferred.

The lowest or I-chang gorge of the Yang-tzï is cut across the Wu-shan limestone, which rises at the rate of about 1,000 feet a mile till the Sin-t'an (Middle Paleozoic) shale appears from beneath it. Further upstream the Ki-sin-ling (Cambro-Ordovician) limestone forms a second gorge, and passing from a dip of 10° to a nearly horizontal position, gives rise to the mesa-like heights above Huang-ling-miau (Fig. A, Plate XXXVII).

The structure of the Paleozoics from Nan-t'ou to I-chang is thus recognized as a simple gentle monocline. The strike is north 50° to 60° east, bending eastward northeast of the Yang-tzï and westward southwest of it. The dip is nearly flat along the northwestern outcrop, and steepens to perhaps 20° to the southwest at the southwestern margin, along the base of the mountains. The section is the southwestern limb of a broad flattish anticline, which is eroded to the underlying granite.

The width of the exposure of the Pre-Cambrian granite is about 12 miles, 17 kilometers, from near Huang-ling-miau to the Lu-kan rocks. The Lu-kan gorge is a canyon across the Ki-sin-ling limestone, which dips northwest, and, being cut diagonally to the strike, forms cliffs along a stretch of 3 miles, 5 kilometers; above Sin-t'an the overlying Middle Paleozoic shale, which we have named from its occurrence at this point, is succeeded by the Wu-shan limestone, dipping 40° northwest and giving rise to the Mi-t'an Gorge. The strike of the strata in this northern limb of the Huang-ling anticline is east by north along the river, but to the westward the beds gradually bend northward till the strike becomes west by north.

The succeeding structure along the river is the K'ui-chóu syncline, which the Yang-tzï skirts along its southern margin. The K'ui-chóu (Permo-Mesozoic) red beds, which dip northward, give rise to a wide area of hills in that direction, and we do not know their extent northeastward and eastward. On the south are high mountains, the outcrop of the Wu-shan limestone along the southern side of the basin.

Above Kuan-t'u-k'óu this mountain range is crossed by the river, which at that place debouches from the lower Wu-shan gorge into the open hill land. The strike of the gorge-making Wu-shan limestone is south 65° east, nearly parallel to the stream, and the dip is 70° north. The form of the fold in the top of the limestone at the contact with the overlying red beds is of a sharp V or keel, which flares widely higher up.

Below Nan-mu-yüan the base of the Wu-shan limestone is marked by the occurrence of black cherts, and it may be assumed that the Sin-

*Gestalt und Gliederung einer Grundlinie in der Morphologie Ostasiens Sitzungsberichte der K. Preuss. Acad. der Wissenschaften, 1900.

t'an (Middle Paleozoic) shale occurs in its proper place below the limestone, but we did not see it.

Between Nan-mu-yüan and Wu-shan-hién the Yang-tzï flows across a sequence of smaller and larger folds, chiefly of the Ki-sin-ling limestone, but at the head of the gorge consisting of the Wu-shan limestone. The sequence will best be understood by reference to the section (Fig. 61) which was sketched as we floated past the magnificent cliffs in which it was exposed. As we could not measure distances, the distribution along the river was noted, and has since been adjusted to Chevalier's map of the Yang-tzï.* Two anticlines and a syncline bring the top of the Ki-sin-ling limestone high above the stream above and below Nan-mu-yüan. For several miles below Ts'ing-shï-tung the course is in the axis of a carinate syncline, a position determined by the Sin-t'an shale, although the canyon is now sunk below that formation in the Ki-sin-ling limestone. The thin beds of the latter dip very steeply, but above them, in a nearly flat position, the Wu-shan forms the upper cliffs. From half a mile above

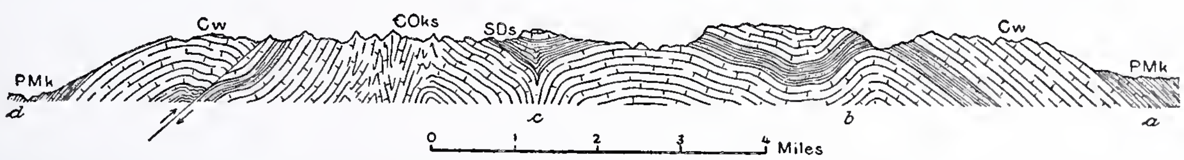

FIG. 61. (Willis).—Wu-shan gorge of the Yang-tzï-kiang. Section between Wu-shan-hién and Kuan-t'ou-k'óu, showing the folds in Paleozoic strata, from Cambro-Ordovician to Carboniferous, inclusive. *a* = Kuan-t'ou-k'óu; *b* = Nan-mu-yüan; *c* = Ts'ing-shï-tung; *d* = Wu-shan-hién.

Ts'ing-shï-tung the synclinal valley extends westward, but is occupied only by a small tributary. The lower part of the Wu-shan gorge is cut across a great anticline of the Ki-sin-ling, the arch extending up to the mountain tops 3,000 feet or more above the river. The inner part of the anticline in the thin-bedded strata near the base of the formation is therefore exposed along the water level, and is seen to be characterized by many sharp folds and possibly by minor overthrusts. The details could not be followed as we passed, but the major structure was clear. Finally, toward the west, the dip is continuous on the northwestern limb of the arch, and the Sin-t'an shale comes in above the limestone. The shale is overlaid by the Wu-shan limestone with the characteristic black chert of the lowest beds. There is a repetition of the shale and limestone with black chert, occasioned by a slight overthrust at this horizon of adjustment, and then follows the mass of the Wu-shan limestone forming the upper part of the Wu-shan gorge. Northwest of the grand arch of the Wu-shan limestone, probably one of the most superb exposures of a fold in the world, the K'ui-chóu red beds occur in the syncline, and the Yang-tzï valley is developed in them for some miles westward.

* R. P. Le Chevalier. Carte du haut Yang-tze.

SECTION ACROSS THE KIU-LUNG-SHAN.

Synclinorium: Wu-shan-hién to Kiu-shï-li-p'u.—Between Wu-shan-hién and Kiu-shï-li-p'u (Ta-ch'ang), a distance of 12.5 miles, 20 kilometers, Fig. 62*a*, the Ta-ning-ho flows across the strike and crosses four anticlines in the Wu-shan (Carboniferous) limestone, and the five adjacent and included synclines, which are occupied by the K'ui-chóu (Permo-Mesozoic) red beds (section, atlas sheet *d* 7). The whole structure is in effect a synclinorium, it being bounded both north and south by higher anticlines; and it is a very flat one, since the difference in altitude for a given stratum such as the top of the Wu-shan limestone, does not exceed 4,500 feet, 1,500 meters. The base of the Wu-shan is not exposed on the highest anticline in this subsection, and the thickness of the K'ui-chóu beds contained in the deepest syncline is probably less than 2,000 feet, 600 meters. A total of 5,500 feet, 1,650 meters, of strata is probably a maximum of what we saw between Wu-shan and Kiu-shï-li-p'u. The folds are not only shallow, but also broad, and the curvature is even,

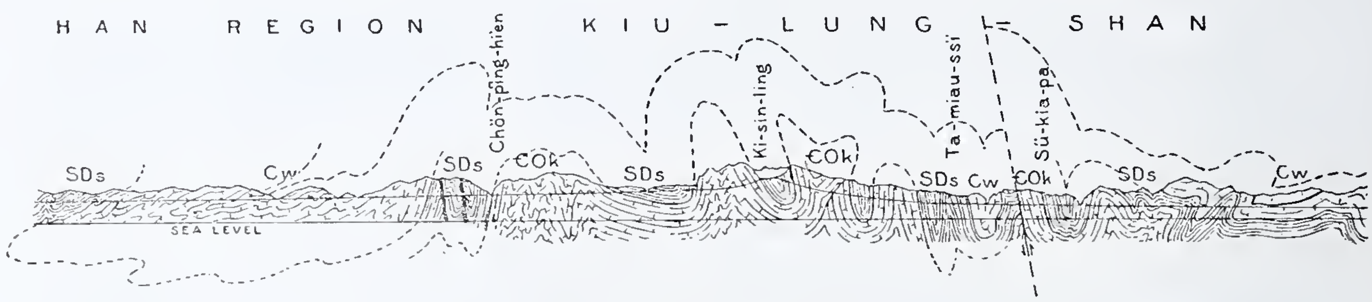

FIG. 62 (Willis).—Geologic section across the Kiu-lung-shan and on the Ta-ning-ho, from Chön-p'ing-hién, Shen-si to Wu-shan-hién, Ssï-ch'uan—reduced from sections in the atlas (continued in Fig. 62*a*).

without sharp accents, except that the central syncline appears to have a keel of the K'ui-chóu red beds pinched in the top of the limestone. The great arches of limestone, trenched by the river in exceedingly narrow canyons with vertical walls, exhibit with rare beauty and clearness the vertical and horizontal distribution of stress and yielding in a massive uniform bed which has undergone moderate flexure.

The pitch of folds, *i. e.*, the inclination of axes, where we crossed them, is sometimes to the west, sometimes to the east. By inspection of the geologic map (Wu-shan-hién sheet *d* 7) it will be seen that the Wu-shan-hién syncline extends both east by north and west by south beyond our observation. If we may trust maps based on Chinese sources for the courses of streams and roads that would follow the synclinal valley, the length of the latter is probably not more than 50 miles, 80 kilometers, and possibly much less. The two little synclines next north in the Ta-ning-ho section appear to be near the western end of the syncline of K'ui-chóu, Hu-peï, in which the Yang-tzï takes its course below the Wu-

shan gorge. The next pitches to the west, that is, we crossed it near its eastern end, and a notable tributary comes in from the west by south. If the syncline were continued 22 miles, 35 kilometers, in that direction in the K'ui-chóu red beds, the valley would strike the Yang-tzï at K'ui-chóu-fu, but there is no evidence of such a valley on the maps. The basin is probably shorter and runs into a high saddle in the Wu-shan limestone. The strike of the folds is also more nearly east and west, and this syncline may extend north of K'ui-chóu-fu or be represented there by the valley of the western branch of the Ta-yang-ho (see general map, Plate VII).

The three towns, San-shï-, Liu-shï-, and Kiu-shï-li-p'u (namely, Thirty-, Sixty-, and Ninety-li village on the imperial highway which once followed the river) lie in a wide synclinorium in the K'ui-chóu beds. The river meanders along and across the strike, and our observations became correspondingly disconnected. Details of minor structures in the K'ui-chóu beds may have escaped us, but the general section is probably nearly that given at the north end of Section AA, atlas sheet *d* 7, and in the south

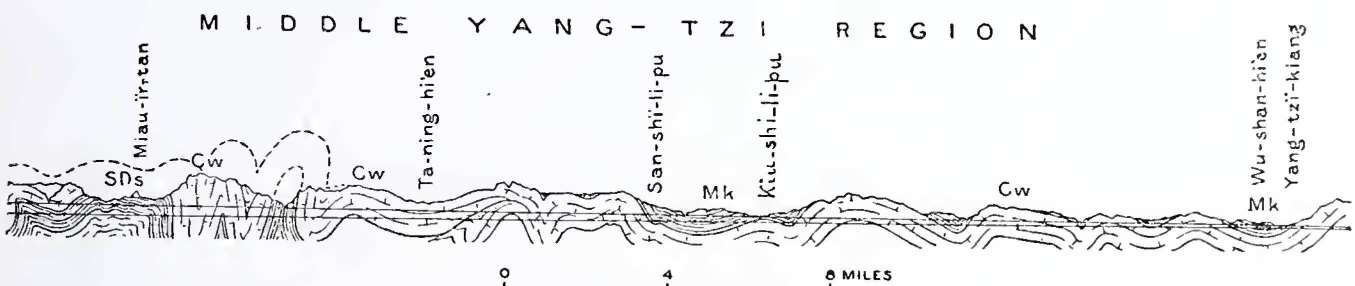

FIG. 62*a*.—Continuation of Fig. 62.

end of Section BB. The deepest syncline may involve 2,000 feet, 600 meters, of K'ui-chóu strata. Along the northern side of the basin, the Wu-shan limestone rises in a fine dip slope. Its counterpart on the south is the Wu-shan anticline, cut by the Yang-tzï in the Wu-shan gorge, and between the two is the synclinorium of which the preceding paragraphs give some account.

*San-shï-li-p'u to Miau-ïr-t'an, 16 miles.**—The fact that the Ta-ning-ho meanders from west to east in the synclinorium between San-shï-li-p'u and Kiu-shï-li-p'u makes it necessary to offset the line of section between those two places. From San-shï-li-p'u upstream to Miau-ïr-t'an we have a direct north-south section, which falls within the Wu-shan-hién atlas sheet, *d* 7, and may be considered by itself, although it is intimately connected with and similar to the section from Miau-ïr-t'an to Sü-kia-pa. The separation of the two is a matter of convenience rather than of fact.

With reference to the section which has been described as a synclinorium south of San-shï-li-p'u, that north of that place may be considered an anticlinorium, since the folds rise higher and expose not only the base

*Atlas sheet *d* 7.

of the Wu-shan limestone, but the underlying Sin-t'an (Middle Paleozoic) shale. Nine-tenths of the section is, however, in the Wu-shan limestone, ranging at the river level from the base of the formation to the top.

Just north of San-shï-li-p'u the K'ui-chóu red beds are involved in a small anticline and syncline, and then rise upon the first great anticline of the Wu-shan. The arch rises sufficiently to expose about one-half of the Wu-shan, and near its center the limestone strata are crumpled on the concave side of the curve. An open syncline of very minor proportions connects this arch with the next one to the north, which is also a relatively small feature. We then come to the great arch which brings up the base of the Carboniferous limestone, as shown in the photograph on the Wu-shan-hién sheet, *d* 6 of the altas, and which contains an overthrust from the north, within the Wu-shan formation. The fact of this overthrust was observed, but its relations to the fold in the higher cliffs could not be, and neither could those below the river level. It follows, therefore, that the internal structure which is delineated on the section is, to a certain extent, hypothetical. The displacement on the fault is probably small, and the dislocation would perhaps not be seen in anything but a deep canyon section. The view of the party surveying in the canyon was taken near the center of this arch (atlas sheet *d* 7).

At Ta-ning-hién and for several miles north of that point, the Wu-shan limestone is exposed in the canyon walls in long sweeping curves of strata. The river is sunk below the top of the limestone at Ta-ning-hién, and the K'ui-chóu red beds do not occur at that town. We do not know whether they appear in the syncline toward the east or the west, but as the streams which here enter the river are small, it is probable that the basin is of limited extent. Were it otherwise, the town would probably lie upon one of the through routes following a valley, which in that case would be developed on the syncline. Two miles north of Ta-ning-hién we saw the limestone somewhat contorted in the axis of the sharp syncline, and the strata north of that point were vertical. The underlying Sin-t'an shales here come to the surface for the first time northwest of the Wu-shan arch, a distance of perhaps 35 miles, 55 kilometers. The fold is a compressed anticline about 3,000 feet, 900 meters, across in the shale, with nearly parallel limbs. Its height could only be inferred. Northward beyond it is a sequence of close folds in the Wu-shan, extending 2.5 miles, 4 kilometers, and comprising two synclines and an anticline. The southern of the two synclines is faulted in the center, and in the northern the strata are very sharply folded together. The whole constitutes a sort of double keel of Wu-shan limestone, which here sinks the black chert horizon perhaps 8,000 or 10,000 feet, 2,400 or 3,000 meters, below the river level.

Approaching Miau-ïr-t'an, the Wu-shan rises steeply into the air and is underlain by the nearly vertical layers of the Sin-t'an shale. The beds turn over in a right-angled fold, and at Miau-ïr-t'an the shale, which is sharply contorted, lies beneath the nearly horizontal limestone capping the hill.

Miau-ïr-t'an to Sü-kia-pa, 12 *miles,* 19 *kilometers.**—This section is a direct continuation of that up to Miau-ïr-t'an, but with reference to the latter may be considered a shallow synclinorium, since the Carboniferous limestone rises higher both north and south. Above Miau-ïr-t'an the Sin-t'an shales extend for a mile and a half at the river level. They rise again from beneath the Wu-shan limestone on two other anticlines. In the northern end of the section the shales reappear and, after extending over an arch of the Ki-sin-ling (Cambro-Ordovician) limestone, they form the broad syncline at Sü-kia-pa. The details of the folds are expressed in Section CC, atlas sheet *d* 6. The deepest point of the synclinorium is at T'an-mu-shu-p'ing, where a stratum of coal in the Wu-shan limestone is extensively mined. The minor folds are numerous and closely appressed, and yet the level of the strata is maintained with remarkable uniformity until we reach the anticline of the Ki-sin-ling limestone south of Sü-kia-pa. At this point the top of the Wu-shan limestone, if it were not eroded, would lie at an altitude of about 7,500 feet above the river. At Sü-kia-pa there is a deep syncline in the Sin-t'an shale, on the northern side of which the Ki-sin-ling limestone again rises with a steep dip.

Between Sü-kia-pa and Wu-shan-hién, a distance of 40.5 miles, 65 kilometers, as measured on the sections, there is no question about the observation and interpretation of any of the major features of the structure. Had our rapid traverse permitted, we would no doubt have added to our knowledge of the details, but it is not probable that the general form or position of any of the larger folds would have been changed from what we noted. Northward from Sü-kia-pa there is, however, a complexity of structure which we did not fully understand in the field, but now interpret as an overthrust fault. This section ends with that fault, and an offset of 5 miles west by north is made for the next.

Tung-kuan-k'ou to Chön-p'ing-hién.†—Between Sü-kia-pa and Tung-kuan-k'ou the Ta-ning-ho meanders in the Sin-t'an shale and an intermediate short section of the Ki-sin-ling limestone, and at Tung-kuan-k'ou it flows in the Wu-shan limestone. Near Sü-kia-pa the Sin-t'an shale lies normally above the Ki-sin-ling limestone, dipping south, as is shown not only by observations of dip on the two formations, but by the

*Fig. 62 and atlas sheets *d* 7 and *d* 6. †Fig. 62 and atlas sheet *d* 6.

occurrence of the Middle Ordovician fossiliferous horizon near the contact. Four kilometers further upstream this same fossiliferous horizon was found at the top of a short section of the limestone, which in turn occurred on top of the Sin-t'an shale. We at first took the limestone for the Wu-shan, since that formation would naturally occur above the Sin-t'an, but afterwards determined by the fossils that it was the Ki-sin-ling. It is probable that this contact is along an overthrust fault, which dips steeply to the south and brings the Ki-sin-ling up over the Sin-t'an shale. The sections are drawn on this interpretation.

The section from Tung-kuan-k'ou to Chön-p'ing-hién is an anticlinorium, in which the Ki-sin-ling limestone is the oldest formation represented and forms the major part of the exposure. We leave the canyon of the Ta-ning-ho at Tung-kuan-k'ou, and the line of section extends north across the mountains at an altitude of 5,500 feet, 1,600 meters, in the pass and 8,500 feet, 2,600 meters, in the adjacent summits. The exposures were much less complete than in the magnificent canyon walls of the Ta-ning-ho, and the structure appeared to be more complex. We therefore present the facts in Section DD, atlas sheet *d* 6, with somewhat less confidence in the accuracy of our observations than for the sections further south, yet in their major features the structures rest upon the recognition of well-defined horizons checked in part by occasional discoveries of fossils, and there is a probability that the drawing correctly represents at least the major facts. At Tung-kuan-k'ou the Wu-shan limestone is represented in a mass which dips steeply to the south and which is characterized by a bed of anthracite coal and by the occurrence of Upper Carboniferous fossils. From sketches made of the distribution of strata in the adjacent mountain on the south, it is believed that this body of limestone is a closed syncline immediately north of a plicated mass of Sin-t'an shale, which is cut by the river as far as the underthrust contact with the Ki-sin-ling limestone. The little brook which flows from the Ki-sin-ling pass to Tung-kuan-k'ou cuts a very remarkable gorge through this outcrop of the Wu-shan, a gorge 1,200 feet, 360 meters, deep and scarcely 100 feet, 30 meters, wide.* Above this little canyon the valley widens out on the shales, which represent the Sin-t'an and which present a nearly uniform steep southern dip. As the exposed thickness of the shales is very much greater than that which they have in normal sequence, it is probable that they are duplicated by isoclinal folding. Near Ta-miau-ssï there is a section of much plicated thin limestones, which we assigned to an anticline of the Ki-sin-ling, and above this occurs a belt of heavy gray flagstones, which we took for the Sin-t'an. A mass of the Ki-sin-ling limestone,

*Plate XLIX.

which is both folded and faulted, follows and is overturned on the Sin-t'an lying in a closed syncline in the summit of the range.

North of the Ki-sin-ling the structure as far as Chön-p'ing-hién presents two great anticlines in the Ki-sin-ling limestone, and a shallow, simple syncline in the Sin-t'an shale. The limestones in the southern anticline present very steep dips. The fold is nearly closed and the strata generally vertical. The section across the second anticline shows many minute plications, a sequence of sharply angular folds which could not be followed through in detail, but which also constitute in general effect a closed fold ending in vertical dips toward the north. The intervening syncline shows the corresponding steep dip northward and gentle dip southward.

North of Chön-p'ing-hién the Wu-shan limestone, which is represented in the heart of the mountains only by the small synclinal keel north of Tung-kuan-k'ou, appears again in a much plicated and overturned syncline between similar bodies of Sin-t'an shale. These structures belong properly to the metamorphic province of the Han basin, and are discussed in that connection.

RELATIONS OF THE SECTION ACROSS THE KIU-LUNG-SHAN.

General discussion.—The section from the Yang-tzï northward across the Kiu-lung-shan exhibits two phases of structure: the southern, of broad gentle folds, between Wu-shan-hién and Ta-ning-hién; and the northern, of closed carinate folds, between Ta-ning-hién and Chön-p'ing-hién. If we extend the section northward we may add a third phase, that of overturned isoclinal folds with development of schistosity, which characterizes the Han province. Considered from north to south this section may be compared with one across the Appalachian province from southeast to northwest, there being in each case a belt of intense deformation, followed by a belt of close folding, which in turn is succeeded by a belt of open folds. The last, in China, extends beyond our ken, and we can not complete the comparison, but it is sufficiently suggestive, so far as it goes. The intensity of deformation lessens from north to south; overfolds in the northern district are toward the south, and the movement was apparently in the same direction.

At first sight another line of inference is suggested: In the main range, south of Chön-p'ing-hién, carinate folding is developed in the slaty limestone and shale of the Ki-sin-ling and Sin-t'an formations, and further south open folding is characteristic of the Wu-shan massive limestone. Had we only these two belts, we might infer that each type of folding is peculiar to a stratigraphic condition, and therefore that the Wu-shan limestone, restored over the main range, should exhibit open folds, whereas the Ki-sin-ling and Sin-t'an, traced beneath the southern belt, should be

more closely appressed. To a certain extent this is probably true; but inasmuch as the higher strata are even more intensely folded in the neighboring Han province than the lower strata are in the main range, there is good ground for the recognition of the increase in intensity northward.

The stratigraphy of the folded rocks is, nevertheless, an important factor in the existing structure. The superficial zone, which yielded to compression, may be described as consisting of: (*a*) The relatively incoherent K'ui-chóu series, which took no effective part, except as load; (*b*) the massive Wu-shan limestone, 4,000 feet, 1,200 meters, thick, a very stiff stratum; (*c*) the shaly Sin-t'an, 2,000 feet, 600 meters, thick, a layer of adjustment; (*d*) the partly slaty, but nevertheless stiff, Ki-sin-ling limestone, 4,500 feet, 1,350 meters thick; and (*e*) the underlying basement of metamorphic rocks. Except on the Yang-tzï the last does not come to the surface along our route, but of its presence at a depth of a few thousand feet there can be no doubt.

This five-membered strut is unsymmetrical in vertical section. The lowest member, presumably also schistose and knitted by intrusives, probably yielded to stress by shearing rather than by folding, and in so yielding may have induced broad dome-structures in the overlying strata, which were 12,000 feet, 3,600 meters, thick or more. This total includes 8,500 feet, 2,550 meters, of limestone, in two members, which are the ones that controlled, and of which the upper is the more competent. Assuming that the deformation was initiated by local doming over the lowest member as it rose in consequence of shortening, the two higher competent limestone members should fold in conformity of one to the other, their diverse movements being adjusted in the intermediate shale. We observe, as we might infer, that the types of folds which have resulted are very broad and shallow and also very narrow and deep. The whole strut, being very competent, could support a long arch; the upper and more competent limestone could independently carry the light load resting upon it (even though concurrent erosion be not considered) and could rise high as the chords of its long arches were shortened; in closer folds it therefore developed keels. The lower limestone, though relatively not so stiff as the upper, was competent to raise the weight of the Sin-t'an shale, plus whatever part of the weight of the still higher strata was not carried by the upper limestone, and thus it too developed broad arches in initial stages of folding, and high keels on closer compression.

The tendency of the whole strut was to develop folds of great height, and thus to localize the horizontal movement in individual anticlines; and the resulting conditions were distinctly unfavorable to development of overthrusts, of which only a few are known as local internal features of folds.

Date of folding.—So far as our own observations go the date of folding in the middle Yang-tzï province is later than the highest beds in the K'ui-chóu series, that is post-Triassic, as the strata appear to be conformable from the Carboniferous up. The conclusion is not final, however, since our observations were incomplete and are in apparent contradiction with those of von Richthofen in the Red Basin of Ssï-ch'uan at Kuang-yüan-hién (Kwang-yuen-hsien) 250 miles, 400 kilometers, further west. He observed an obvious unconformity at the horizon beneath the Permo-Mesozoic, at which we observed apparent conformity of bedding, in repeated exposures and over a wide area. Having described a section across the folded Paleozoic strata, he states as follows:*

"With this anticline and the narrow folds of the southern limb the older formations come to an end. The slopes higher up are crowned by escarpments of brightly colored limestone. With gentle southward dip which is unconformable to the strata 5 (Silurian) and which is continuous beyond this point, these descend gradually to the river and reach the valley of Ta-tung-tzï. We therewith reached a region which, in relation to structure and age of the formations is quite distinct, the true basin of Ssï-ch'uan. The stratigraphy is grouped as follows, from below upwards; that is, from north to south:

A. A limestone formation 1,200 feet thick; beginning with bright-colored (red, yellow, green, and white) thin-bedded limestones, upon which lie thick-bedded limestones, at first mottled with red and green, but higher up of yellow color. Then there succeeds much yellow dolomite, which is overlaid by grayish-white nodular limestone. This limestone formation, which strikes from west to east and dips 30° to the south, forms for some distance the last steep bluffs along the river. It occurs in other parts of Ssï-ch'uan and probably belongs to the Permian or Triassic.

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* China, vol. II, p. 603. "Mit dieser Antikline und den engen Faltungen des südlichen Flügels endigen die älteren Formationen. Hoch oben sieht man die Gehänge von Steilwänden bunter Kalke gekrönt. Allmälig ziehen diese mit sanfter südlicher Neigung, die von hier an ausschliesslich herrscht, abnorm auf den Schichten (5) gelagert, nach dem Fluss herab und erreichen den Thalboden bei Tatung-tsz. Wir gelangen damit in eine hinsichtlich der Tektonik und des Alters der Formationen ganz verschiedene Gegend, das eigentliche Becken von Sz-tshwan. Die Schichtgebilde gruppiren sich infolgender Weise von unten nach oben, d. i. von Norden nach Süden:

A. Eine 1,200 Fuss mächtige Kalkstein formation. Sie beginnt mit bunten (rothen, gelben, grünen, und weissen) dünnplattigen Kalken. Darauf liegen dickbänkige Kalke, erst grün und roth gefleckt, weiter hinauf von gelber Farbe. Dann folgt viel gelber Dolomit, der von weisslichgrauen klotzigen Kalken überlagert wird.—Diese Kalkstein formation, welche W—O streicht und 30° südlich fällt, bildet für eine Strecke dic letzten schroffen Wände am Fluss. Sie findet sich auch in anderen Theilen von Sz-tshwan und ist wahrscheinlich dem Perm oder der Trias angehörig.

B. Kohlenführende Formation von *Kwang-yuen*. Unmittelbar über dem Kalkstein lagern:
   (1) Sandige und thonig sandige Gesteine von gelben und grauen Färbungen, meist dünn geschichtet. Im untersten Theil deuten alte Halden auf die Existenz eincs Kohlenflözes. Machtigkeit 1,000 Fuss.
   (2) Ein 200 Fuss mächtiger Wechsel von grauen pflanzenführenden Schieferthonen and mürben Sandsteinen, welche mit Pflanzenstengeln erfüllt sind. Darin liegen zwei Flöze deren jedes drei bis vier Fuss machtig ist. * * * Die Pflanzenreste bestimmte Herr Prof. Schenk als zum Unteren Jura gehörig.
   (3) Dicke Banke von groben Conglomeraten. Die Rollstücke, welche aus Kalksteinen und festen Sandsteinen bestehen, sind im unteren Theil am gröbsten. Mächtigkeit, 300 Fuss.
   (4) Gelbe Sandsteine, mit thonigen Schichten wechselnd, 1,000 Fuss.
   (5) Thonige, zum Theil rothgefärbte Sandsteine, 600 Fuss.
   (6) Dickbänkige grünliche Sandsteine, weich und mürbe, wie alle Sandsteine der Formation, 500 Fuss.

B. Coal-bearing formation of Kuang-yüan. Just above the limestones there come:
- (1) Sandy and clayey sandy rocks of yellow and gray coloring, generally thinly bedded. In the lower part are old mine dumps, which indicate the presence of a coal-seam. Thickness, 1,000 feet.
- (2) Alternating plant-bearing shales and soft sandstones, which are filled with remains of plant stems. Thickness, 200 feet. This member contains two coal-beds 3 to 4 feet thick. * * * The remains of plants have been determined by Prof. Schenk as belonging to the lower Jura.
- (3) Heavy beds of coarse conglomerate. The pebbles, which consist of limestone and firm sandstone, are coarsest toward the bottom. Thickness, 300 feet.
- (4) Yellow sandstone, alternating with clayey strata. Thickness, 1,000 feet.
- (5) Clayey sandstones, in part reddish. Thickness, 600 feet.
- (6) Heavy-bedded greenish sandstone, soft and crumbling, as are all sandstones of the formation. Thickness, 500 feet.

The following comment by Lóczy* appears to have a bearing on the relations of the Mesozoic and Paleozoic rocks of the basin of Ssï-ch'uan, and to cover in part the section observed by von Richthofen (Kwang-yuén-hsien and Quan-juön-shien being one and the same place):

> The fossils of the great Red Basin are almost exclusively remains of plants. I collected plants near the coal-mines of the mountains of Lin-tschin-shien, Hoani-pu in western Se-tschuen, and near Quan-juön-shien. The remains from the first locality are considered by A. Schenk to be Rhetic or Triassic, while those from Hoani-pu and Quan-juön belong to the middle Jura (Dogger).
>
> It is noteworthy that the supposed Rhetic strata of Lin-tschin-shien are more involved in the folding of the underlying strata than those which belong to the higher sandstones of the Dogger.

The section observed by us on the Ta-ning-ho presents, above the Wu-shan (Carboniferous) limestone, a series which is similar to but thinner than that at Kuang-yüan-hién. Von Richthofen's red thin-bedded limestone, forming the lower part of A, corresponds in color and position with the red shale, 400 feet, 120 meters, thick, of our section of the base of the K'ui-chóu; the differences of thickness and clayey or calcareous nature aside. The dolomite of A agrees with the limestone (possibly dolomitic) from which we obtained the fossils that Girty regards as of late Paleozoic, probably Permian, age. Above the limestone we observed coal-bearing sandstones similar to B, the lower Jura of von Richthofen's section, and the plants collected on the Yang-tzï by him and Pumpelly point to the

* "Die Versteinerungen des grossen rothen Beckens sind fast ausschliesslich pflanzliche Ueberreste. Ich sammelte Pflanzen in der Nähe der Kohlengruben der Gebirge von Lin-tschin-shien, Hoani-pu, im westlichen Se-tschuen, und bei Quan-juön-shien. Die vom ersten Orte stammenden Ueberreste bezeichnete A. Schenk als rhaetisch oder triadisch, die aus Hoani-pu und Quan-juön stammenden als der mittleren Jura (Dogger) angehörend.

"Es ist bemerkenswerth, dass die für rhaetisch gehaltenen Schichten von Lin-tschin-shien mehr an der Faltung des Grundgebirges theilnehmen, als die dem Dogger angehörenden höheren Sandstein-Schichten." Ergebnisse der Reise des Grafen Széchenyi, vol. III, p. 211; also vol. I, p. 685.

same or a closely related age. The sequences are essentially the same, although we have probably less than 1,000 feet, 300 meters, of Permo-Mesozoic as opposed to von Richthofen's estimate of 2,400 feet. We do not include the beds 3 to 6 of B, since they appear to be later than anything we saw on the Ta-ning-ho or Yang-tzï.

If the facts are as observed in northern Ssï-ch'uan and on the middle Yang-tzï, the episodes of sedimentation and folding have been diverse in the two regions as follows:

Period.	Northern Ssï-ch'uan.	Middle Yang-tzï.
Later Mesozoic and possibly early Tertiary.	Deposition of beds 4 to 6 inclusive. No apparent unconformity of dip; yet possible unconformity, not noted by von Richthofen, but suggested by the coarse conglomerate (3), and by the observation of Lóczy.	Beds corresponding to 4, 5, and 6 not observed, but may be present; their relation to folding unknown. Pronounced folding either before or after deposition of beds 4, 5, and 6 in Ssï-ch'uan.
Permo-Mesozoic including "lower Jura" of Schenk.	Deposition of the beds A and lower part of B (1 and 2). Pronounced folding and deep erosion.	Deposition of the K'ui-chóu series, including coal-beds. No folding and no obvious erosion; probable hiatus without distinct unconformity.
Upper Carboniferous.	Limestone deposition.	Limestone deposition.

From this comparison we are led to infer that: (*a*) In northern Ssï-ch'uan there was an episode of folding at the close of the Carboniferous; whereas (*b*) in the middle Yang-tzï region there was none until some time, sooner or later, after the Triassic, and then there did occur pronounced deformation comparable to that which had already taken place in Ssï-ch'uan. Intermediately the K'ui-chóu series was laid down and was somewhat affected by the later folding in Ssï-ch'uan as well as in the Yang-tzï region.*

*See sections by Obrutschov across the western Ts'in-ling-shan, Mongolia, and Central Asia (in Russian), vol. II, Plate II, p. 356; also in Suess, Face de la Terre, vol. III, Fig. 35, p. 270.

CHAPTER XIV.

GEOLOGY OF CENTRAL SHEN-SI.

By Bailey Willis and Eliot Blackwelder.

OBSERVATIONS IN THE HAN PROVINCE.

TS'IN-LING-SHAN AND HAN VALLEY.

General statement.—The Ts'in-ling mountains and the Han valley constitute a special geologic province, by reason of the regional metamorphism which the rocks have suffered. This province we designate simply the Han Province.

Along our route the T'ai-shan (Archean) complex is not represented. Apart from intrusive masses, among which granite predominates, the rocks are of sedimentary origin and include some Algonkian, the Paleozoic from Cambro-Ordovician to Carboniferous, and probably some Mesozoic. They are converted into metamorphic rocks, among which we distinguish certain series or formations that we correlate tentatively with those of the Yang-tzï province, where the strata are not altered and the age is determined by fossils.

We entered this geologic province at the north, where metamorphism is most intense, and proceeded diagonally across it toward the south; and we observed the true sequence of formations, as it is exposed on the Ta-ning-ho and Yang-tzï sections, only after we had left the region of metamorphism. It follows that we reached a partial and tentative understanding of the relations of the schists only through the subsequent study of our notes, and we no doubt failed to observe important facts, which we might have seen had we known where to look for distinctive evidence. The geology of the Ts'in-ling-shan and Han valley will offer but little difficulty if thoroughly surveyed. Even the pioneer work of von Richthofen approximated the true relations, and the supplementary reconnaissances by Lóczy and ourselves enable us to sketch a reasonably reliable outline of the sequence and distribution of the rocks. In the following pages we jointly discuss our observations and our inferences of stratigraphy and structure, for each locality, thus departing from the plan pursued in other chapters of this report. The available data are not sufficient to furnish an adequate basis for the more systematic treatment.

In order to have available a general term for the metamorphic Paleozoic and Mesozoic rocks of the Han province, we shall designate them the

Han system. The system comprises representatives of the Ki-sin-ling, Sin-t'an, Wu-shan, and K'ui-chóu divisions, as recognized among the terranes of the Yang-tzï valley; and also the similar rocks constituting the Heï-shui series of the northern Ts'in-ling-shan. The latter series is probably equivalent to the Paleozoic of the Han system, but is geographically separated from the area of typical occurrence, the Han valley, and is lithologically somewhat dissimilar.

The following table shows the tentative correlations which we have reached, between the series of the metamorphic Han province, and those of the non-metamorphic Yang-tzï province.

Terranes of the Han Province.	Terranes of the Yang-tzï Province.
Shï-ts'üan sandstone (Jurassic): Reddish cross-bedded sandstone with basal conglomerate moderately indurated. Not metamorphosed.	Not seen but probably present, possibly equivalent to the coal-bearing strata of the upper K'ui-chóu.
K'ui-chóu schists (Permo-Mesozoic): Silvery mica-schists with local seams of coal; include thin layers of marble, magnetite-phyllite, and gneiss. On Han river, spotted biotite-sericite-schists with garnets are characteristic rocks.	*K'ui-chóu red beds (Permo-Mesozoic):* Massive red shales and sandy strata with beds of gray marine limestone. Coal-seams occur locally in upper portion of formation.
Wu-shan argillite and limestone (Carboniferous): Black impure limestone and slate with local seams of anthracite. North of Han river limestone largely silicified and shaly portions converted into schists. Probably represented in the southern exposures of the Heï-shui series.	*Wu-shan limestone (Carboniferous):* Thick-bedded dark limestone with thin local shales and quartzite near the base; lower portion rich in round nodules of black flint; local coal beds.
Sin-t'an argillites (Middle Paleozoic): Green slates, partly hard and siliceous, but partly clay-slate. In Han valley and north represented by gray-green phyllite and quartz-slate. Probably represented by a considerable thickness in the Heï-shui series.	*Sin-t'an shale (Middle Paleozoic):* Massive green shale with local black and brown shales and thin green quartzite.
Ki-sin-ling limestone (Cambro-Ordovician): Hard gray limestones. North of Chön-p'ing-hién seen only on the Han river above Han-wan-ch'öng. Probably represented in the northern exposures of the Heï-shui series.	*Ki-sin-ling limestone (Cambro-Ordovician):* Massive gray limestone with little or no flint. Thin-bedded near the base and locally shaly near the top; fossils ranging from Lower Cambrian to Middle-Ordovician.
Ts'in-ling schists (Algonkian): Green chlorite-schists with thin beds of siliceous limestone and quartzite; locally biotite-schist and sericite-schist.	*Algonkian rocks:* Argillaceous, ferruginous limestone, micaceous quartzite, etc., seen as erratics in Nan-t'ou till; not observed in place.
	Huang-ling granite (Pre-Cambrian): Gray quartz-diorite, probably associated with various schists, slates, and basic intrusive rocks.

DESCRIPTION AND INFERENCE.

In order to pursue our inference from the sound basis of definite stratigraphy of the non-metamorphic strata to the vague correlations we may suggest for the metamorphic rocks of the Ts'in-ling-shan, we retrace the steps of our journey, proceeding in this description from south to north. We go from Chön-p'ing-hién to Hing-an-fu on the Han, up the Han to Shï-ts'üan-hién, and thence northward across the Ts'in-ling-shan.

Chön-p'ing-hién to Hing-an-fu.—Chön-p'ing-hién (lat. 31° 49', long. 109° 34', atlas sheet *d* 6) is near the southern margin of the district of that regional metamorphism which characterizes the Han system. From the limestones which occur from 0.5 to 3.5 miles, 1 to 6 kilometers, south of the town, we collected Cambrian fossils, and we have no doubt that the shales which appear on the north as well as on the south of the limestone anticline are the Middle Paleozoic Sin-t'an shales. Following the Nan-kiang northward from Chön-p'ing-hién, we first cross dull olive-green and gray argillites. These argillites have been subjected to sufficient dynamic action to crush and shear them in many places and even to develop an imperfect slaty cleavage. They have been intruded by a number of thick gabbro dikes.

Three miles below Chön-p'ing-hién the Nan-kiang receives a large tributary from the west. On the south side of this stream the black limestones and slates, similar to the Wu-shan limestone on the Yang-tzï, overlie the green argillites and continue in closed recumbent and contorted folds to Ku-niu-tu and beyond. The rocks are very dark argillaceous and frequently bituminous limestones interbedded with gray slates and pyritic black slate, which locally contain thin coal-seams.

Two or 3 miles, 5 kilometers, north of Ku-niu-tu greenish slates reappear. They resemble in color and in general composition the green argillite near Chön-p'ing-hién, differing from that formation chiefly in the more prominent development of slaty cleavage. The rock is a moderately hard olive-green slate, which is well but not regularly cleaved. The original bedding is indicated by specimens which show planes of stratification at angles of about 25° to the slaty cleavage. The slate is intruded by irregular bodies of gabbro, some of which are several hundred feet in width. The contact between gabbro and slate is sharp, and the latter has been locally altered by the intrusion to a chlorite-hornfels. It is probable that these slates are a reappearance of the Sin-t'an shale.

The structure of the belt between Chön-p'ing-hién and the green slates north of Ku-niu-tu is apparently that of a syncline, whose northern limb is overturned southward. Our observations of dip have been used in making up the forms shown in the northern end of the section, Fig. 62, and also on the geologic atlas sheet *d* 6. The dips are gentle and to the north throughout; but there are axes of minor anticlines and synclines, especially noticeable in gray limestone near the base of the Wu-shan formation north of Shï-chai-ho, and also in black slaty limestone near Ku-niu-tu. Certain observed folds near Ku-niu-tu are shown in Figs. 63, 64, and 65.

Two miles, 3 kilometers, south of Pai-kiu-hia the green slates of the Sin-t'an are succeeded by black limestone and slate, through which the

Nan-kiang cuts a gorge, which is narrower than the canyon immediately above or below. These rocks are dark impure limestones, sometimes siliceous, but usually argillaceous. They are associated with dense buff dolomites, black and gray slates, and anthracite coal, which is mined in the vicinity of Pai-kiu-hia from seams in the black limestone. In the same locality intrusions of gabbro, similar to those mentioned in the last paragraph, break through the hard limestone as well as the slates. We regard this outcrop as the lower massive part of the Wu-shan, which occurs in the same relation north of Chön-p'ing-hién. The dip near Pai-kiu-hia is steep to the north or vertical.

Slaty black strata extend the sequence to the forks of the Nan-kiang (atlas sheet *d* 5), west of which we particularly noted an outcrop of buff limestone, strike NW., dip 50° NE., which strikingly resembles a limestone of the Heï-shui series of the northern Ts'in-ling-shan. It will be

FIGS. 63 AND 64.—Folds in Carboniferous argillites near Ku-niu-tu, Shen-si.

seen that the strike is here nearly parallel to our course, but it is not persistent in any one trend. It ranges from east-west to north-south, and the dip is accordingly now north, now east. Going north-northwest we follow the Wu-shan argillite nearly to Pa-kua-miau, and remain near the base of the formation all the way. In the vicinity of Tsöng-kia-pa the blue-gray limestones and slates contain quartz-mica-schists, in which small, but workable, seams of anthracite occur, and northwestward coaly black slates and siliceous argillites continue.

About 3 miles, 5 kilometers, north of Tsöng-kia-pa blue-black siliceous argillite lies upon a greenish conglomerate-schist. The rock is a chlorite-sericite-schist, in which are imbedded distorted pebbles of white quartz, bits of feldspar, and limestone. None of the constituents is recognizable as to age. There is no doubt but that this conglomerate lies in contact with the Wu-shan (Carboniferous) limestone, but we are not sure whether above or below it. If above, it is at the base of the Permo-Mesozoic series, a horizon at which we are led to expect an unconformity on account of the abrupt change in physical conditions. If below the Wu-shan, it is at the base of that formation in contact with the Sin-t'an shale. Further south on the Ta-ning-ho we observed apparent conformity at this horizon,

Ku-niu-tu, Shen-si, atlas sheet d 6. View of canyon of the Nan-kiang east of the town, showing characteristic outcrop of somewhat schistose argillite and limestone of the Wu-shan, Carboniferous, formation.

yet the fossils collected above and below indicate that Silurian and Devonian time are represented by very meager sediments. Much further north, in Shan-si, we found an unconformity by erosion at the base of the Carboniferous. Somewhere in the intermediate zone there should be the conglomerates of the littoral between the flat lowland and the clean sea bottom. This conglomerate north of Tsöng-kia-pa may be such an occurrence. The character of the Wu-shan strata is that of the base of the formation, and the position indicated by our observations of strike and dip, traced from the contact with the Sin-t'an argillites south of Pai-kiu-hia, is close to or on that contact. The sequence from older to younger is from the conglomerate to the Wu-shan, unless the strata are overturned. A conglomerate was observed at this horizon on the Han near Yü-fang-p'ing, atlas sheet *a* 4. On these grounds we regard this conglomerate as being at the base of the Wu-shan.


FIG. 65.—Fold overthrust southward near Ku-niu-tu, Shen-si.

The Hung-shui-ho, which flows eastward past Tsöng-kia-pa, brings down large quantities of gabbro, but we did not see any intrusives in place in this part of the section.

About 2 miles, 3 kilometers, south of Pa-kua-miau the Wu-shan formation is succeeded by hard gneissic graywackes, which appear to come in over the black slates and argillites. These schists are brown-gray or russet-colored rocks, in which micas have developed in parallel arrangement. That the rock is, however, only moderately metamorphosed is indicated by the fact that the larger grains of quartz and feldspar in the original graywacke are still unaltered. The graywackes continue in a northwesterly direction, with northeasterly dips, and become associated near Pa-li-kuan with silvery gray slates, which recur in the valley southeast of P'ing-li-hién. In the interval of 5 miles, 8 kilometers, our route was occasionally on black slates and siliceous argillites of the Wu-shan formation, either because we meandered across the contact or because of outcrops on minor folds.

The graywacke and silvery slates of this section, from south of Pa-kua-miau to P'ing-li are unfamiliar rocks, not like the Sin-t'an shale in any metamorphic phase of that formation which we recognized, and yet in sequence with the Wu-shan limestone. The structural relations are

such that it is not probable the graywacke-schists can be the Sin-t'an underlying the Wu-shan, for the schists appear to be above that formation. The schists are such rocks as may well be derived by metamorphism from the K'ui-chóu red beds, since they are both sandy and ferruginous. Thus from their apparent stratigraphic position and their lithologic character we infer that they are the representatives of the Permo-Mesozoic, even though they are considerably metamorphosed.

The coal-mine east of P'ing-li-hién is worked on a small vein, which is very badly squeezed and faulted. Silvery schists of the K'ui-chóu extend along the river, and the blue-black siliceous limestone of the Wu-shan outcrops both north and south of them. It is difficult to say in what horizon the faulted coal occurs, but it appears to be in the schist in an overturned syncline. All the beds dip north from 10° to 40°, and the structure is apparently that of a syncline of K'ui-chóu and Wu-shan schists, crushed under massive bodies of the lower Wu-shan limestone, which is overthrust from the north. The strike which, south of P'ing-li, trends north-northwest, now changes to east-west. Thirty-five miles, 56 kilometers, west by north from P'ing-li, on the Han river, we crossed a similar zone of apparent overthrusting of the Wu-shan on the K'ui-chóu, and we believe the structure to be a continuous major feature of the region.

North of P'ing-li-hién, the Wu-shan formation occurs in its characteristic phase of blue-black calcareous and siliceous argillite, often a cliff-making rock, much jointed and somewhat slaty. The beds dip both north and southeast, on sharp local folds which pitch steeply northeast. Coal is mined at several places.

The hills near Liu-wang-miau and thence northward to Hing-an-fu are composed of monotonous gray phyllites and brownish mica-schists, which extend northwestward across the Han-kiang. Near Lau-hién the schists contain coal, and in some of the slates streaks of hematite occur. The mineral is mined in a small way as an ore of iron. This occurrence of coal and iron ore, together with the general lithologic character of the schists, leads us to place the rocks in the K'ui-chóu formation.

We thus recognize two distinct coal-bearing formations in this region, one of them equivalent to the Wu-shan limestone, and the other to the K'ui-chóu beds of the Yang-tzï valley. This opinion is supported by the fact that coal occurs in both formations in eastern Ssï-ch'uan, and also in both the Carboniferous* and the Jurassic† in the northeastern part of the same province.

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* Von Richthofen, China, vol. II, p. 60. (At Tschau-tien coal-seams occur in the midst of a thick black limestone. Carboniferous fossils, such as *Spirifer lineatus*, occur in the limestone both above and below the coal horizon.)

† *Ibid.*, p. 603. (The coal-beds at Kwang-yüen overlie beds which are believed to be Permian or Triassic. The coal-bearing shales themselves contain fossils similar to those of the European Jurassic.)

Hing-an-fu to Shï-ts'üan-hién.—We ran the stretch of 105 miles, 169 kilometers, from Shï-ts'üan-hién to Hing-an-fu in boats in 28 hours, not counting stops. The river flows in a canyon 1,000 to 4,000 feet, 300 to 1,200 meters, deep, frequently between precipitous bluffs, which rise 100 feet, 30 meters, or so above the water's edge, and which are in general surmounted by long steep slopes. Throughout the entire distance there is a practically continuous section of the limestones, slates, and schists of the Han system, with occasional large dikes.

For 8 to 10 miles, 13 to 16 kilometers, above Hing-an-fu the banks consist of the characteristic gray phyllites, which we consider to be the K'ui-chóu schists. Near Siau-tau-ho coal is mined in black siliceous slate, which we assign to the Wu-shan formation. The contact between the K'ui-chóu schists and this belt of the Wu-shan probably crosses the river in a west by north direction, between Lan-ho-k'ou and Liu-shui-tién (atlas sheet *b* 4). Extended southeasterly, it passes south of Nu-wang-miau, where we have already noted it.

The coal a mile below Siau-tau-ho is a bony anthracite with much pyrite. It is mined at intervals from the river to the summit of the ridges, the dip being nearly vertical, though contorted. A score of openings may be seen, and in the half dozen visited the bunches of coal vary from 1 to 12 feet, .3 to 3.5 meters, in width, up to 30 feet, 10 meters, in height, and from 1 to several hundred meters in length. The lenses represent formerly continuous but now badly squeezed beds, which may have been 4 or 5 feet thick. They are repeated on an anticline, which is well-exposed in some of the upper workings. Although the coal is very inferior, it is quite extensively mined and shipped down the river. The price at the river bank is 75 cash a picul, about 70 cents a ton.

Just at Siau-tau-ho there are other mines in which the dip is 15° to 40° northeast. We regard this occurrence as the southwestern side of a local syncline and the vertical dips a mile down the river as the adjacent anticline, northeast of which the beds dip under the succeeding K'ui-chóu schist.

Between Ta-tau-ho and a sharp bend a mile south by west from Han-wang-chöng we observed chiefly soft olive and gray phyllites, locally dotted with small octahedra of magnetite and of the general character of the K'ui-chóu schists; but the very sharp bend that the Tung-ho enters 4 miles, 6.5 kilometers, southwest of Ta-tau-ho carries the river into limestone, which we take to be the Wu-shan formation. The dip observed in this limestone, 35° north, and that noted in the schists near Huan-ku-t'an, 10° southwest, form a broad flat syncline. We interpret the structure as a shallow basin of K'ui-chóu schists on Wu-shan limestone. If the

Wu-shan coals occur they crop out southwest of the Han-kiang and it is possible that they lie at gentler dips and are less squeezed than near Siau-tau-ho; but the schistosity, which strikes northwest across the basin and dips 67° northeast, indicates that the coal would be disturbed. The schists are cut by large masses of basic igneous rock, similar in appearance to the gabbros that occur further south. Tzï-yang-hién lies in the syncline, and for convenience of statement the name Tzï-yang may be applied to the basin.

The Tzï-yang basin and the syncline at Siau-tau-ho are adjacent, but apparently not connected. If they were connected, the coal-beds which strike north of the river at Siau-tau-ho should recross it near Ta-tau-ho, striking southwest and dipping northwest. We saw no such recurrence of the coal nor any structure parallel to that strike. We infer that the two synclines are separated by an overthrust, which replaces the anticline that should lie between them and is of such displacement as to bring into close proximity two folds whose axes are at right angles to one another.

Between Han-wang-ch'öng and Lién-hua-shï (atlas sheet *a* 4) a nearly complete section of the Han system is apparently displayed. Northwest of Han-wang-ch'öng the canyon is roughly parallel to the strike of a series of blue-gray shaly limestones, with which are associated thinner members of gray slates and schists. There is a notable lack of coal-veins and black rocks in general. The dip of the limestone is usually steep, being 45° to 80° to the northeast and 60° to the southwest. It seems to be an anticline which is locally overturned southward. Near Süé-hua the limestone passes south of the river, and the rock of the banks is greenish slate or schist; but thence for 6 miles upstream to beyond Han-yang-p'ing, the limestone prevails. We regard the limestone as the lowest formation of the Han system, the Ki-sin-ling (Cambro-Ordovician), but we here see only its uppermost strata, and we do not know of any other occurrence of it in the Han valley.

If our identification of the Ki-sin-ling limestone in this stretch above Han-wang-ch'öng and that of the K'ui-chóu schists in the Tzï-yang basin both be correct, it is apparent that the relation between the two can not be one of regular structure, since the Cambro-Ordovician is thus brought over the Mesozoic. The inferences as to age are consistent only with the further inference that the Ki-sin-ling limestone is overthrust upon the K'ui-chóu schists. The position of this overthrust falls in line with that noted as probable at P'ing-li-hién and near Siau-tau-ho, and the fact that the three sections, which we thus observed in a distance of 70 miles, 112 kilometers, along the course of the fault, sustain one another gives us confidence in the suggestion.

A mile above Han-yang-p'ing the supposed Ki-sin-ling limestone is succeeded by gray-green siliceous slates, of the character of the metamorphosed Sin-t'an formation. The dip is 20° north and the sequence apparently regular.

In the tortuous course above Han-yang-p'ing the river three times crosses a contact between green slates and overlying blue-black limestone, a contact such as that which characterizes the base of the Wu-shan formation. At or near it we noted, in two sections, a conglomerate, which we regard as probably a basal conglomerate corresponding with that seen south of Pa-kua-miau (atlas sheet *c* 5). Upstream toward Yü-fang-p'ing there occur the calcareous black and coaly argillites of the Wu-shan, which are, however, much contorted, the dip varying from 25° to 80° and the strike from nearly east-west to northeast-southwest, through an angle of 135°. The contorted beds are also dislocated and overthrust.

Two miles, 3 kilometers, below Lién-hua-shï silky gray phyllites succeed the limestone in the normal position and with the lithologic appearance of the K'ui-chóu schists. Thus the sequence of the Han system, from the Ki-sin-ling limestone to the K'ui-chóu schists, appears to be accounted for from Han-wang-ch'öng to this point.

Below Lién-hua-shï (Lily-flower-rock) the schists are intruded by a mass of light-gray granite about 2 miles, 3 kilometers, wide, across which the Han has cut a very narrow and beautiful gorge; north of the granite the schists extend for 2 miles, 3 kilometers, to a contact with the dark quartzitic limestones that in this district appear to represent part of the Wu-shan. The strata are associated with coaly beds and characteristic blue-black argillites, which form the south bank opposite Shï-ts'üan-hién.

In the vicinity of Shï-ts'üan-hién the valley of the Han is wide, with a long slope on the north and hills of moderate altitude on the south. The northern bank and part of the southern, 1.5 to 4 miles, 2 to 6.5 kilometers, below the city, consist of Shï-ts'üan sandstone which we describe as Jurassic (?). We have next to consider the northwestern extension of the structure seen near Lién-hua-shï. The occurrence of the K'ui-chóu schists near Lién-hua-shï, between the Wu-shan formation on the north and south, is probably a syncline, though the Wu-shan on the north may be more or less overthrust. In the canyon of the Han west of Shï-ts'üan-hién, this belt is crossed again. The dip is from 50° to 70° toward the northeast throughout, but we do not doubt that the strata are overturned from the northeast and that the structure is a complicated closed syncline. A section extending 7 miles, 11 kilometers, from Shï-ts'üan-hién up the river was paced off during our stay at the city, and the following sequence was noted. Thicknesses are given to suggest the relative extent

of the rocks in the section, but it should be understood that they have no value as measures of the actual or original thickness of any of the strata, since they are greatly increased by folding and schistosity. Fossils were searched for, but not found. This section ends abruptly against white felsitic aplite, associated with massive greenstone. The relation of these igneous rocks to each other is not known, but they are evidently intrusive in the sedimentary series.

ROCKS EXPOSED IN THE HAN CANYON ABOVE SHÏ-TS'ÜAN-HIÉN.

Formation.	Character.	Width of Outcrop.	
		Feet.	*Meters.*
Wu-shan formation. Northeastern limb overturned.	Blue limestone and dark carbonaceous limestone.	600	180
	Spotted quartz-biotite-schists; presumably infolded K'ui-chóu.	1,000	300
	Bluish limestone, sericite-schists, and black coaly schists. Contains a dike of black amphibolite.	300	100
K'ui-chóu schists; synclinal.	Soft green slates or schistose argillites with local gneissic quartzites.	9,000	2,700
Wu-shan formation. Northwestern limb much repeated by folding.	Blue-black slaty limestone, partially schistose. Quartz-mica-schist (50 feet). Dark massive limestone, much contorted.	2,600	780
	Mica-schist.	150	45
	Blue-black slaty limestone.	1,000	300
	Silvery gray biotite-schist.	100	30
	Blue-black flinty limestone, containing one thin layer of coarsely crystalline white limestone.	3,800	1,150

Shï-ts'üan-hién to Ts'ai-kia-kuan.—North of Shï-ts'üan-hién the conditions for observation of the rocks are less favorable than in the canyon of the Han. For 20 miles, 32 kilometers, until the P'u-ho is reached, the way is over low hills covered with vegetation. The soil is deep and the rock in the banks of streams usually decayed. Varieties of schists look alike, and the only rock of the Han system which is conspicuous is the blue-black argillite, limestone, or quartzite, which we later came to identify as of Wu-shan, Carboniferous, age. Along the P'u-ho the rocks are more strongly metamorphosed than on the Han; indeed, so much more strongly that we did not regard them as probably Paleozoic until we had reviewed our notes in the light of the Han section; and with the exception of a characteristic Wu-shan rock north of Ta-ho-pa, there are none which we can assign to a definite horizon in the Han system.

The following paragraphs contain our observations en route, together with the inferences drawn from later knowledge of the stratigraphy.

For a distance of 4 miles, 6.5 kilometers, north of Shï-ts'üan-hién the Han system is covered by the conglomeratic sandstones of much

more recent date—the Shï-ts'üan formation. North of this area of the younger rocks the metamorphosed Paleozoics reappear as closely folded schists and limestones. The main road runs nearly parallel to the strike of these beds, but crosses them gradually. In the vicinity of Ssï-yen-pa the prevailing rock is a silvery sericite-garnet schist spotted with biotite. It contains at least one thin member of buff crystalline limestone, which is rich in muscovite and has a tendency to cleave readily in parallel slabs without regard to the planes of stratification. South of Fan-chan-tan hard blue-black siliceous limestone forms a narrows in the valley. Adjacent to it, and probably overlying it, are soft coaly black schists like those on the Han river opposite Shï-ts'üan-hién. The limestone is brecciated in numerous places, and white veins fill the fractures. It appears to be doubled in a closed fold. We consider it an anticline of the Wu-shan appearing through the K'ui-chóu schists.

North of the black limestone belt the garnetiferous mica-schists and buff limestone bed, seen south of it, reappear, and similar schists form the surface to the head of the valley. At one bend of the stream, however, 2 miles, 3 kilometers, north of Fan-chan-tan, we noted a small outcrop of much-folded black argillite, and near the divide, on which is situated the temple of T'óu-mön-ssï, the black soils observable in the neighboring slopes indicate that coaly schists occur extensively.

Between the pass and Liang-ho the road follows a tributary valley which has been excavated along the strike of some dark bluish micaceous limestones and mica-schists. The strata are frequently contorted and the limestone is sometimes sheared into thin sheets. The hills at Liang-ho are composed of spotted biotite-garnet-schists containing several layers of limestone a few feet in thickness, which are crystalline gray and buff rocks with veins of quartz and abundant spangles of muscovite. Rocks of this character continue from Liang-ho northwestward to Ta-ho-pa. In this section the mica-schists are probably stratigraphically higher than the blue-gray limestone.

Immediately north of Ta-ho-pa the P'u-ho runs through a narrow canyon, which has been cut across the strike of a vertical blue-black quartz rock. It is a dense black or banded formation, which we think is the silicified limestone above Ssï-yen-pa, except that it is perhaps more thoroughly quartzose. The outcrop appears to be a little more than 2,000 feet, 600 meters, wide at Ta-ho-pa. To the north of these narrows the rocks are soft mica-schists and gneisses, which resemble those at Liang-ho and are believed to be the same formation recurring.

The structure from Fan-chan-tan northward to Ta-ho-pa may be a succession of anticlines and synclines, in which the Wu-shan and K'ui-

chóu formations appear alternately. Such is probably the case to the pass, T'óu-mön-ssï, but north of that we lose track of the rocks. The gray limestone and mica-schists of the vicinity of Liang-ho may probably be K'ui-chóu schists in a syncline. The black quartzite of Ta-ho-pa, which is probably folded in an anticline or syncline, we identify as the characteristic quartzite of the Wu-shan (Carboniferous). Beyond this we are unable to extend any inference of age.

At San-ho-k'óu we came upon gray banded marble which is partly schistose, the cleavage planes being coated with biotite and muscovite crystals. One or 2 miles north of that village gray gneissic quartzite was encountered, but as exposures were not frequent along that portion of the road, its relationships to the marble and schists were not determined. It is cut by dikes of fine-grained gray granite. The sequence is interrupted near Shï-t'ing-ho by large intrusions of porphyritic pink granite, but is resumed after a lapse of not more than 2 miles, 3 kilometers, with the reappearance of the dark schists and gneisses. A coarse-grained white marble is quarried at Ssï-móu-ti. The rock is almost gneissoid in structure, and contains well-formed tabular crystals of muscovite; in a general way it resembles the San-ho-k'óu marble, and it may well be a second occurrence of that member.

From Ssï-móu-ti to Ts'ai-kia-kuan the complex of schists and mica-gneisses continues. All are cut by granitic intrusions of various dimensions, and the gneiss sometimes shows plicated bands. About half-way between the two villages we found what appeared to be a conglomerate-schist; the dark biotite-schist contained numerous lenticular bodies of quartz, arranged in roughly parallel layers.

About 2 miles north of Ts'ai-kia-kuan the schist series terminates against the great mass of intrusive granite, which forms the central portion of the Ts'in-ling range, and extends in a belt 11 miles wide, to Chang-k'óu-shï.

Chang-k'óu-shï to Liu-yüé-ho.—The northern part of the high ridges of the Ts'in-ling-shan, as far north as Lung-t'an-ssï and Chuang-kia-p'u, is composed of gray, greenish, and buff-brown slaty limestone, with thin-bedded quartzite and thick beds of gray to black slate. Black coaly slates are interbedded with the limestone just below Chang-k'óu-shï, and coal was found by von Richthofen* and by David† in similar strata not far to the west of our route. The limestones themselves closely resemble those seen near Ts'öng-kia-pa (atlas sheet *d* 5), which we consider Carboniferous. Though generally slaty the rocks are not greatly altered, and therefore appear to be much younger than the schists of the Han system,

* China, vol. II, p. 566. † *Ibid.*, p. 628.

with which they are, nevertheless, in all probability correctly correlated. Beyond a general correlation we can not go, as we did not observe any distinctive horizons which we can now recognize.

To distinguish this series, which we can identify only as Paleozoic and which may correspond to more or less of the Han system, we may call it the Heï-shui system after the river of that name, which crosses it west of our route.

The structure of the Heï-shui system is probably not very intricate, if one had a key to the stratigraphic sequence, but there are large areas of monotonous slates, which exhibit numerous folds. Under the conditions of our journey the structure eluded us except in its larger features. The following is quoted from Willis's notes written at Chang-k'óu-shï, after ascending the canyon:

> Although the rocks are continuously exposed from Siau-wang-kién to Chang-k'óu-shï no definite section was obtained, as the strata present great similarity throughout considerable thicknesses, and are repeated by obscure but numerous folds and possibly by thrusts. In general the strike of the series varies from N. 80° E. to S. 55° E. At Siau-wang-kién the dip is northward, as low as 30°. In about 2 miles it changes to southward over an anticlinal axis and continues so for about 3 miles, becoming vertical. Again northward and also flat dips come in. Where well exposed, the strata exhibit isoclinal folds overturned southward. About 2 miles below Chang-k'óu-shï gray limestone appears accompanied by black slate and apparently beneath the argillite and quartzite. It is much silicified and exhibits tension crevices, which weather out as cavities. Slaty cleavage is highly developed in the black calcareous argillites accompanying the limestone. Flesh-colored and greenish quartzites form a conspicuous member of the series apparently above, but closely related to, the limestone.

The structure thus interpreted is expressed graphically, and necessarily more definitely than we know, in the section, geologic sheet *a* 2. The actual folds are no doubt more intricate. On an anticlinal axis 2.5 miles, 4 kilometers, south of Lung-t'an-ssï, which is an eastern extension of the anticline near Siau-wang-kién, the lowest beds immediately beneath greenish slates are quartzite above conglomerate of quartz pebbles in quartzite; and large masses of similar conglomerate and blocks of crystalline white marble were seen 4.5 miles, 7 kilometers, southeast of Lung-t'an-ssï, on the trail from Mu-tzï-p'ing. These appear to be the lowest beds occurring in this district. The slates are lithologically like the Sin-t'an (Middle Paleozoic) and the marbles may correspond with those seen in the northern section, presently to be described; if so, they are probably Cambro-Ordovician.

A plausible statement of the structure according to these lithologic identifications is that an anticlinorium, which along the anticline of Siau-wang-kién brings up earlier Paleozoic strata, is succeeded on the

south by a synclinorium of Carboniferous rocks, which are overturned southward.

The principal area of the Heï-shui system is limited on the north by a belt of intrusive granite, which is about 4 miles, 6 kilometers, across on the Heï-shui-ho and also on the river north of Mu-tzï-p'ing. North of the granite is an occurrence of limestone and schists, which we place with the Heï-shui system as unclassified Paleozoic; whether the strata of the northern area are equivalent to those of the southern we do not know; they are probably earlier. The section on the Heï-shui-ho is short. It contains massive impure limestone of green-gray color, underlain by gray mica-schists and greenish graywackes, which are somewhat schistose. Talus which rolls down the mountain north of Liu-yué-ho contains masses of slaty maroon conglomerate. The planes of cleavage make a large angle with the layers of pebbles, which mark the original lines of bedding. In the coarsest phase of the conglomerate the pebbles attain a diameter of 5 to 8 inches, 12 to 20 centimeters. They consist of buff-white limestone, white, reddish, and blue-gray quartz, and banded flint. The fragments, although somewhat rounded, are relatively angular and ill assorted. It is not possible to determine whether the pebbles were derived from the Kan-yü-wan strata, but all the constituents noted could have been secured therefrom. The slight alteration of the conglomerate indicates that it is not so old as the Kan-yü-wan schists, which occur north of it, and the color of the slate suggests the basal red shales of the Cambrian in northeastern China. Unfortunately the rock was not observed in place, and we did not see its relation to the graywackes, slates, and impure limestones, which occur south of it, but in all probability it is at their base and above the Kan-yü-wan schists. An observation by von Richthofen along a route somewhat to the west of ours tends to support this view.* At Pai-kia-tién he found similar slates and limestones resting on green schists in apparent unconformity. In the eastern section of these rocks, observed between T'ié-k'iau (atlas sheet *a* 1) and the granite, there is a distinct syncline, in which the sequence from below upward is mica-schist, white quartzite, and gray limestone. A basal contact was not seen, probably because the line between the older Kan-yü-wan schist and the mica-schist was overlooked in traversing the canyon. The white quartzite is a conspicuous formation 600 or 700 feet, 180 to 200 meters, thick, which in homogeneity and texture resembled white marble and was like quartzites that, in the Appalachian province of America, pass in a short distance into limestone. The overlying gray limestone was massively bedded and not greatly altered.

* China, vol. II, p. 582

A

B

A. Three miles southeast of Lung-t'an-ssï, Shen-si, atlas sheet a 2. Characteristic view of high summits and upper valleys of the Ts'in-ling-shan, showing topography of Heï-shui schists above the region of deep canyons which skirts the northern margin of the mountains.

B. In canyon between Siau-wang-kién and Chiang-k'óu-shï, Shen-si, atlas sheet a 2. View of outcrop of slates of Heï-shui series. In the shrine on the cliff is a small idol and the stones set on end are offerings to the spirit of the dangerous ford. Coolies of the expedition.

This sequence of maroon conglomerate, mica-schist and graywacke, white quartzite, and gray limestone more nearly resembles the Sinian (Cambro-Ordovician) than any other Paleozoic terrane. The quartzite is not known elsewhere in that system, but may be regarded as a local replacement of a sandy limestone. The other members of the Heï-shui system in this northern section are such as might be derived by metamorphism from the red Man-t'o shale and Ki-chóu limestone, which constitute the Sinian of Shan-si. We have shown reason to think that the strata of the southern section of the Heï-shui system represent the Middle Paleozoic and Carboniferous; and thus the entire series is presumably equivalent to the Paleozoic.

Liu-yüé-ho to Heï-shui-ho.—North of Liu-yüé-ho is a belt of strata, which underlie those of the Heï-shui system, are apparently separated from them by an unconformity, and are more strongly metamorphosed. We therefore regard them as Pre-Cambrian, and to distinguish them from other terranes of that era designate them the Kan-yü-wan schists.

The Kan-yü-wan schists include mica-gneiss and schist, chlorite-schist, conglomerate-schist, limestone, and massive argillite. Into these have been intruded granites and other igneous rocks. The entire mass is folded, and both folds and contacts are now more or less obscured by the development of schistosity, which is nearly uniform at high angles regardless of the original rock structures. Although the sedimentary rocks are thus altered, the igneous intrusions, with a few exceptions, appear to be essentially unchanged.

South of Chóu-chï-hién, along the northern slope of the Ts'in-ling mountains, the Kan-yü-wan schists are exposed in a belt 4 miles broad. The northern limit* is a fault-scarp, with alluvium covering the downthrown side; the southern edge of the exposure is believed to be situated near Liu-yüé-ho. The following is the observed section:

In the front of the mountains at Heï-shui-k'óu the rocks are gray schists, mostly silky sericite types such as commonly develop from the severe metamorphism of pure clay-rocks. Near the town these contain a member of pale-gray siliceous limestone, about 100 feet, 30 meters, thick. The schists and limestones are cut by quartz veins, several dikes of greenstone schist, and one of gray aplite (?). No other igneous rocks, except the large granitic intrusions, were found at any other locality in the Ts'in-ling-shan.

Farther up stream the sericitic schists become greenish on account of an increase in the content of chlorite, and in places they develop into true chlorite-phyllites. From 1.5 to 4 miles, 2 to 6 kilometers, above

* The basal gneiss observed by von Richthofen (China, vol. II, p. 581) does not appear in this locality.

Heï-shui-k'óu the chlorite-schists predominate almost to the exclusion of other rocks. At rare intervals rocks of unquestionable sedimentary origin occur, interstratified with the schists. One of these is a 10-foot, 3-meter, layer of dense white quartzite, which the river crosses less than a mile below Kan-yü-wan. In the ridge opposite that village the sericite-chlorite-schist contains numerous crushed ellipsoidal pebbles of white quartz, which range in length from 1 to 6 inches and all lie with their longer axes parallel to the plane of schistosity. This is evidently a schistose conglomerate, and it is possible that it marks a line of division between a younger and an older series. Definite relations, however, were not ascertained. The chloritic schists continue about 2 miles, 3 kilometers, above Kan-yü-wan, and contain in that interval two nearly vertical members of dense gray limestone, each 100 to 200 feet, 30 to 60 meters, thick.

The schists are gradually succeeded by pale greenish and purplish argillites, with which are included thin members of siliceous white limestone and chlorite-phyllite. All of these are hard resistant rocks and where their upturned edges protrude rugged mountains occur. They extend to the vicinity of Liu-yüé-ho.

The strata which have been described as the Kan-yü-wan schists are for the most part severely metamorphosed and characterized by a prevailing greenish color, due to the prevalence of chlorite. The only other rocks in China with which we can compare them are the Wu-t'ai schists of central Shan-si, and the resemblance between the two systems is such that von Richthofen felt justified in extending the name "Wu-t'ai schichten" to these Kan-yü-wan schists.* We regard this correlation as probably correct, although not yet well substantiated.

The granites of the Ts'in-ling mountains.—Lithologically the granites mentioned in the foregoing pages belong to two varieties, exemplified by a specimen from the north side of the Ts'in-ling pass, and by observations near Shï-t'ing-ho.

The former is a black and white rock of uniform medium grain. It is composed of glassy quartz, microcline and orthoclase, black biotite, dark green hornblende, sphene, apatite, and epidote. This is the prevailing granite of the central and northern portions of the Ts'in-ling uplift, in the line of our route of travel. On the south side of the pass the color of the granite is clear-gray with less distinction between the crystals of dark and light minerals. Structurally it is massive and not visibly gneissoid; it is cut by no dikes, except of white aplite and pegmatite. The granite at Ïr-ling-p'u is similar to this, and the Lién-hua-shï rock has the same aspect.

* China, vol. II, p. 581

The granite at Shï-t'ing-ho, although possibly derived by segregation from the magma which produced the rock at Wön-kung-miau, is very unlike it in character. As a whole it is a massive pale reddish granite of porphyritic texture. The phenocrysts are well-formed crystals of flesh-red orthoclase, 1 to 4 centimeters in length, which are frequently twinned, according to the Carlsbad law. The matrix is tolerably fine-grained and consists largely of orthoclase, quartz, and several dark ferro-magnesian minerals. A tendency toward gneissoid structure is apparent in some of the exposures.

Intrusive contacts of these granite masses with the sedimentary schists of the Heï-shui system were observed at several points. Between Liu-yüé-ho and Ïr-ling-p'u the northern contact of the granite of that region shows a zone of evident contact metamorphism about 100 feet, 30 meters, wide, between an impure limestone and a flesh-gray granite of medium grain composed of glassy feldspar, pale quartz, and biotite. In the intervening zone the limestone is very dense and hard, and near the contact it contains crystals of pink orthoclase, quartz, and a little biotite. The rock is not schistose, however, and retains the general appearance of the limestone.

South of Chang-k'óu-shï a contact of the Wön-kung-miau granite with the Heï-shui system was seen in the ravine west of the trail. Small dikes of granite extend 3 or 4 feet, about a meter, into the sediments, and fragments of schist occur in the granite. Near the contact the slaty Paleozoic rocks have been converted into dark biotite-schists. The influence of the intrusion does not extend far into the sediments, however, and within less than a mile all effects had disappeared. This corresponds with observations near Ïr-ling-p'u and indicates that the batholites of the Ts'in-lings have not been important factors in the general metamorphosis of the sedimentary rocks.

The age of the granite in the Ts'in-ling-shan is shown by the above-described contacts to be less than that of the strata of the Heï-shui series; that is, in all probability, Post-Carboniferous. The granite at Lién-hua-shï, which is lithologically similar, cuts schists that we assign to the K'ui-chóu of late Triassic or Jurassic date. While possibly not contemporaneous, the igneous masses throughout the Han province appear to belong to a single epoch of intrusion, which we are thus led to place in the middle Mesozoic, allowing sufficient time to elapse after the deposition of the K'ui-chóu to permit folding and metamorphism of the strata. The granites may have been intruded at the close of the deformation, but not earlier, as they do not exhibit its effects.

The gabbros and related basic rocks occur in the form of dikes, frequently of large size. Some of them have suffered but little metamorphism,

while others have recrystallized into amphibolites. None of them, however, are schistose, with the exception of the greenstone and aplite west of Shï-ts'üan-hién. Like the granites, they pierce the strata of the Han system, and it is not improbable that they date from the epoch of deformation, which appears to have taken place in the Mesozoic.

A few dikes, which were observed associated with the Ts'in-ling schists at Heï-shui-k'óu, may well be older than any of the igneous rocks previously mentioned, as they are thoroughly metamorphosed.

LATE MESOZOIC.

SHÏ-TS'ÜAN SANDSTONE.

The Shï-ts'üan sandstone consists of conglomerate and reddish arkose sandstone. It was seen only in the vicinity of Shï-ts'üan on the Han river, where it is exposed in an open lowland bordered by mountains of Paleozoic strata (see Plate XLIV). The prevailing rock is a firm coarse-grained sandstone, composed of heterogeneous materials. It contains seams of conglomerates, which become more numerous downward and finally predominate at the base of the formation. The pebbles range up to 12 inches, 30 centimeters, in diameter, and consist chiefly of dark limestones and schists derived from the Han system. The strata are not folded, but are gently tilted toward the west and southwest. Cross-bedding, inclined at angles of about 20° toward the west, is very prominent in the sandy portions, which have the character of a delta deposit, the cross-bedding being more regular and persistent in its dips than it usually is among the worked and reworked accumulations of river flood-plains, or in subaerial deposits. The distribution of the mass in the river valley probably does not signify that it was deposited by the existing river; it is more likely that the valley has developed on the soft sandstone. The southern margin is straight like a normal fault, and we therefore regard the mass as a down-faulted block. It is possible that the faulting produced a depression, in which the sandstone gathered as the wash of streams on the tilted slope. We observed a thickness of 320 feet, 97 meters, but the actual thickness of the formation may be much greater.

Although the contact at the base of this sandstone and conglomerate was not observed, the fragments of the Han river rocks included in the formation prove beyond question that the contact is unconformable. The sandstone was evidently deposited at a period later than the folding, metamorphism, and igneous activity, which have so conspicuously affected the strata of the Han system.

According to Pére David,* who noted the rocks at Shï-ts'üan-hién while descending the river in 1873, similar reddish sandstone and conglomerate outcrop near Ch'öng-ku-hién on the upper Han. Beyond this brief mention, however, we know of no previous description of the Shï-ts'üan formation, in the Han valley. We are inclined to regard it as equivalent to the conglomerate and sandstone described by von Richthofen† and later by Lóczy‡ from northern Ssï-ch'uan.

Von Richthofen's section is given on a subsequent page. There is nothing in the lower members A and B1 and 2 resembling the strata at Shï-ts'üan-hién, but the strata B3 and 4 are essentially the same. The heavy conglomerate B3 marks a change of climatic or topographic conditions, if not an unconformity, and it is probable that a stratum which contains pebbles of the Paleozoic rocks should overlap upon them. On this comparison we regard the Shï-ts'üan sandstone as probably equivalent to B3 and 4 and assign it to a later Mesozoic age than the "lower Jura" or Triassic of von Richthofen's section.

PLEISTOCENE.

The Huang-t'u formation of northern China was not seen along our route across the Ts'in-ling-shan and through the Han valley. Remnants of alluvial soil remain here and there, on cut terraces in the mountains, but they do not constitute a formation. Recent river alluvium and gravels are not extensive along the streams, where they flow in canyons. Only in the basin of Hing-an-fu did we observe a considerable deposit of fluviatile material. It consists of gravels carried by the Han, and is not very recent, as the pebbles of crystalline rocks, which it contains, are generally decayed. Glacial deposits do not occur, and even the lofty summit of the Ta-pai-shan (12,500 feet, 3,750 meters), exhibits no topographic features suggestive of glaciation. A fuller account of the Pleistocene features is given in the chapter on the physiography of southern Shen-si.

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* Journal de mon 3me Voyage d'Exploration dans l'Empire Chinois, vol. II, p. 49.

† China, vol. II, p. 603.

‡ Ergebnisse der Reise des Grafen Béla Széchenyi in Ost-Asien, vol. I, p. 439.

A

B

A. Triangulation point 2½ miles northwest of Lung-t'an-ssi, atlas sheet a 2, altitude 5,800 feet. Looking south across canyon to main divide of the Ts'in-ling-shan, showing general uniformity of summit altitudes presumably inherited from a formerly existing peneplain, and profiles of old valleys, especially apparent in the foreground above recent canyon; in general a characteristic view of the dissected surface of Ts'in-ling stage in hard slates.

B. Ridge 4 miles southeast of Lau-hién, Shen-si, atlas sheet c 4, altitude about 2,800 feet. View northeastward across the heights which are taken to represent the Ts'in-ling surface, which is traversed by deep canyons on soft schists and is poorly preserved.

CHAPTER XV.

PHYSIOGRAPHY OF SOUTHERN SHEN-SI.

By Bailey Willis.

INTRODUCTION.

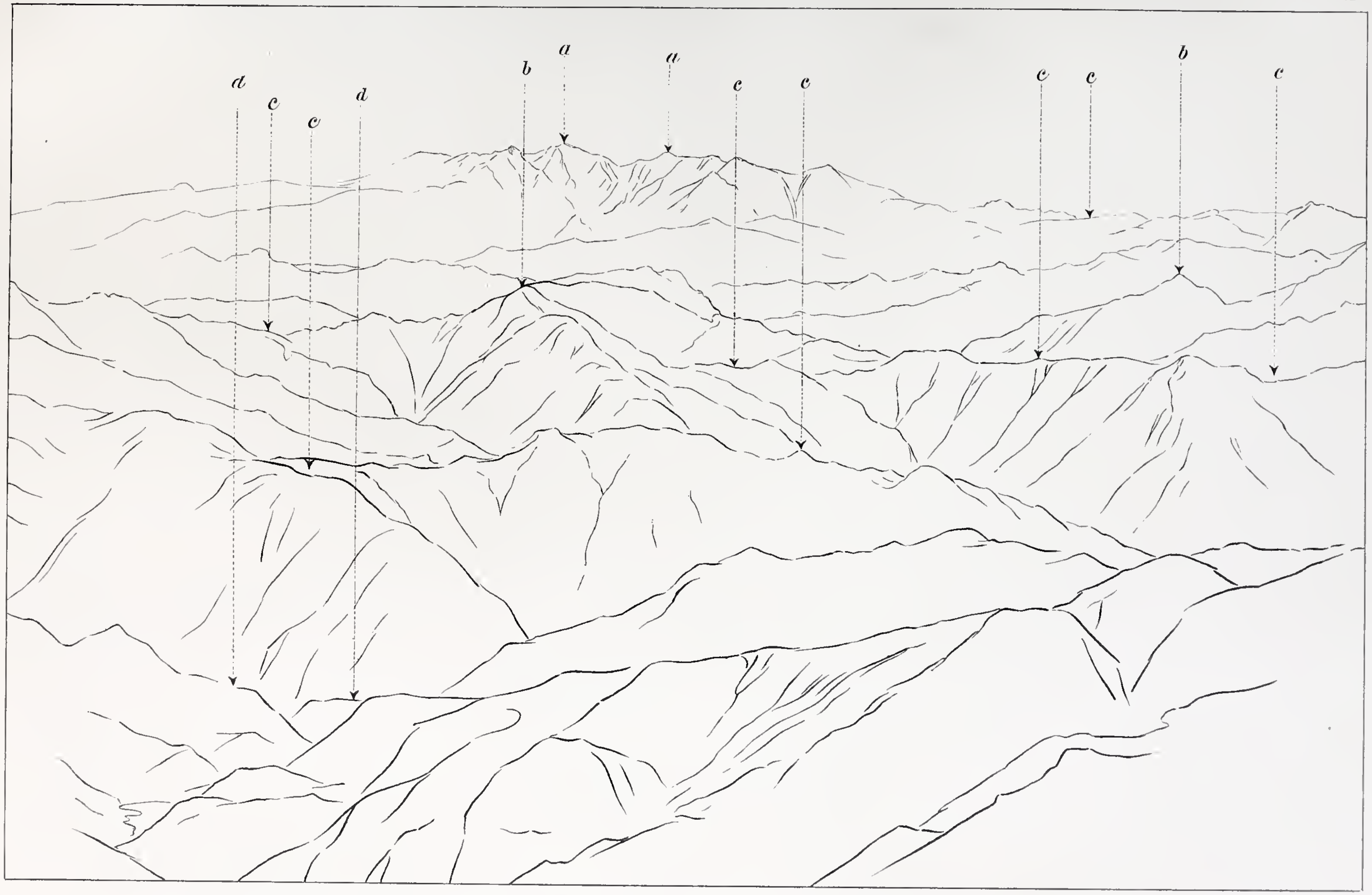
The region to be described in the following pages is that mountainous district of central China lying south of latitude 34° on both sides of the meridian 109° W., and extending southward beyond the Yang-tzï, outside the range of our observations. On the east it is bounded by the lower valley of the Han river and westward it extends to the plateaus of Tibet. We entered the mountains from the Weï valley, about 50 miles west of Si-an-fu, near the town of Chóu-chï-hién, and crossed the Ts'in-ling-shan, a range from 7,000 to 12,250 feet, 2,100 to 3,735 meters, high and 100 miles, 160 kilometers, wide, to the Han valley at Shï-ts'üan-hién. Thence we followed the river through a picturesque canyon to Hing-an-fu, a city located in a wider part of the valley above a lower canyon. At Hing-an-fu we left the Han-kiang and proceeded across several ridges and valleys of a mountain mass, 175 miles, 280 kilometers, wide and 6,000 to 11,000 feet, 1,800 to 3,350 meters, high, which from its main divide we shall call the Kiu-lung-shan, to the Yang-tzï-kiang. On the great river we took boats through the gorges to I-chang.

In the course of this journey we crossed two geological provinces, which are distinguished by the character, though not by the age, of the rocks. The northern, which comprises the Ts'in-ling-shan and the valley of the Han, presents an area of schistose metamorphic rocks, which as a rule offer little resistance to erosion, but are traversed by occasional ledges of hard quartzite and intruded by large masses of granite, that maintain more or less conspicuous elevations. The southern geologic province, on the other hand, is characterized chiefly by limestones, with which are associated narrow belts of relatively soft shales. The limestones form great mountain ranges, across which the principal streams cut deep canyons, but on the shales there are narrow longitudinal valleys.

The major features of the region may be enumerated as follows: The northern mountains constitute two ranges, the Ta-hua-shan and the Ts'in-ling-shan, which lie *en échelon*, stretching east and west, south of the valley of the Weï. Their relations have already been discussed in connection with the structural geology of central Shan-si, in which the uplifted masses

are described as raised fault-blocks, and their northern slopes as fault-scarps. The Ta-hua-shan was not seen by us on its southern and south-eastern flank, which is part of the watershed of the lower Han river. The Ts'in-ling-shan forms the east-west divide between the Yellow river and the Yang-tzï watershed, and we use the name as far south as the latitude of Shï-ts'üan-hién, where there is an east-west depression which for a short distance is the valley of the Han; but it is probable that there are local Chinese names for different parts of the range, and that this application might not correspond with native usage. Among important physiographic features, the basin of Han-chung-fu, to the west of our route, is one of the most interesting, but we were unable to visit it. The part of the Han river which we followed runs through high mountains, for which we learned no general native name. We shall speak of them as the Mountains of the Han, including under that term the heights on both sides of the river, from the basin of Han-chung-fu eastward. In traversing them the Han cuts a deep canyon, which widens at Hing-an-fu to a valley 8 or 10 miles, 13 or 16 kilometers, across on the course of the river from east to west, and probably 30 or 40 miles, 50 or 60 kilometers, long from north to south. This basin is floored with recent gravels, and appears to have other features than those which would follow from a simple widening of the river valley. Between the Han-kiang and the Yang-tzï-kiang is a very extensive mountain mass with many ramifying valleys and ridges, most of them of notable altitude and as yet very little known. The district is one in which the Jesuit fathers, 200 years ago, located but few points astronomically, and which most travelers have passed by, taking one of the great highways, either up the Yang-tzï or the Han, or from Han-chung-fu southward into the Red Basin of Ssï-ch'uan. In 1903–'04, however, a British party under Col. C. E. Manifold made extensive surveys in this district. The main divide became known to us as the Kiu-lung-shan or Nine-dragon range, and we used that name to designate the mountains south of those of the Han valley; but we are unable to draw any line between the mountainous regions thus distinguished, and indeed there is no line to be drawn, as the northern ridges of the Kiu-lung-shan extend to the Han. The northern and southern watersheds of the Kiu-lung-shan are both traversed by canyons, of which those that are cut by tributaries of the Yang-tzï are remarkably profound and narrow. The celebrated gorges of that river transect ranges of great height and end at I-chang, where, 960 miles from its mouth, the mighty stream enters its flood-plain.

The physiography of the region thus sketched differs from that of North China in being comparatively simple in development. We were unable to recognize any very aged upland surface, which might corre-



Sketch of the Ta-pai-shan, Shen-si, and nearer summits of the Ts'ing-ling-shan; from peak west of Siau-wang-kién, atlas sheet a2; looking southwest. aa=heights at 11,000 to 12,000 feet above sea. bb, summits of old mature surface. cc, high valley levels. dd, lower valley terraces above deep canyons.

spond to the Peï-t'ai stage as exhibited in the Wu-t'ai-shan, the oldest features present being those of a mature topography, which more closely resembles the T'ang-hién stage of northern China, yet is presumably younger. No epoch of aggradation such as the Hin-chóu stage is distinguishable, the Huang-t'u being almost unknown south of the Weï valley, but in South China as well as in North, the epoch of recent uplift, the Fön-ho stage, is represented by great heights and correspondingly profound canyons.

DESCRIPTION OF FEATURES ALONG THE ROUTE.

Range of the Ta-hua-shan.—Entering the wide valley of the Weï-ho, we followed the base of the Ta-hua-shan from a point about 10 miles, 16 kilometers, west of Tung-kuan-t'ing to its western end at Lin-tung. In the vicinity of Hua-yin-miau, where it apparently reaches its greatest altitude, the range rises abruptly to about 4,000 feet, 1,200 meters, above the plain (Fig. A, Plate XXI). It appears to consist chiefly of homogeneous granite, which is sheared by major joint-planes approximately in east-west and north-south directions. The face is composed of stupendous precipices, one of which exhibits a smooth plane, probably 2,500 feet in height, at a slope of 70°. The summits are in some instances broad-topped, but in general acute, and the face is interrupted by canyons, which narrow in about 300 feet, 90 meters, above the plain and include a very narrow ravine in their bottoms. Toward the west the bold character due to vertical jointing gives way to more nearly pyramidal forms, apparently because the vertical joints pass gradually into a gentler attitude and finally become horizontal. In Fig. B, Plate XXI, the aspect of the western end of the range, where it presents a much gentler slope than near Hua-yin-miau, is shown. The photograph exhibits the lower summits, which are truncated by the even slope of the fault-scarp, and the terraced deposit of loess that rises from the plain to a height of 300 or 400 feet, about 100 meters. While we made no study of the range sufficient to justify more than general inferences, the facts indicate that the upper surfaces present a mature topography, and that the valleys in the dissected fault-scarp record the progress of uplift in their wider upper portions and in the narrow lower ravines, 300 feet, 90 meters, deep. The loess which lies upon the lower part of the slope has been described as possibly a wind-blown drift or as a portion of the valley plain carried up with the uplifted rock mass.

Front of the Ts'in-ling-shan.—The northern front of the Ts'in-ling-shan, like that of the Hua-shan, varies in steepness. If it be anywhere as precipitous as that of the Hua-shan near Hua-yin-miau, it is so south of

Si-an-fu, but it is very doubtful if such be the case, though the range appeared higher and bolder in the distant view we had from the city wall than in those sections which we saw more nearly. The views (Plate XXII) present it as we observed it east and west of our route, south of Chóu-chï-hién, and it is also represented on atlas sheet *a* I. Fig. A shows the straight front, which bounds the plain almost by a ruled line, and which is here and there characterized by the flat facets that cut diagonally across the structure of the schists and are regarded as elements of the fault-plane. Toward the west the slope shown in Fig. B does not retain these features of a scarp; it is less even, becomes gentler, and appears to pass into a warped surface. It is inferred that the fault dies out westward.

Though the fault-scarp of the range is a structural feature, its history is to be read only in the canyons which have developed in the uplifted block, for the downthrow is buried and the schists of the mountain front are severed from any connections they formerly had.

Heart of the Ts'in-ling-shan.—The canyon of the Heï-shui-ho may be taken as a type of the channels cut in the northern Ts'in-ling-shan, as it compares closely with the description, given by von Richthofen and Père David, of those by which they crossed far to the east and west of it. Yet it is less precipitous than their accounts might lead one to expect. The view from above Liu-yüé-ho (atlas sheet *a* I) gives its principal features at a glance: an inner canyon 1,300 feet, 395 meters, deep, which is bolder in the massive granite, wider in the weaker schists; an outer canyon which opens upwards; and shoulders on the mountain spurs, which, being covered with deep alluvial soil, are cultivated and are therefore conspicuous on the wooded mountain sides. If the river level at Liu-yüé-ho is 2,000 feet, 600 meters, above sea, these benches occur near 3,400, 4,500, and 5,500 feet, 1,035, 1,375, and 1,675 meters, on the spur followed by the trail to Ïr-ling-p'u, and for that immediate locality they are well shown on the topographic and geologic maps. They also occur elsewhere in the canyons of the Heï-shui-ho and its tributaries, rising with the rising profiles of the streams, but we were not able to map them in detail.

The stream which flows past Mu-tzï-p'ing, 10 miles, 16 kilometers, east of the Heï-shui-ho, is sunk in a similar but wilder canyon, cut across ledges of massive limestone and quartzite that leave all too scant room for the mountaineer's path in the bottom gorge, but support benches at intervals in the higher slopes.

It is noted by von Richthofen and by Père David that the deep and narrow canyons are confined to the lower courses of the streams, and that the upper valleys are more open and hospitable. We observed the same contrast in those valleys whose headwaters do not flow across harder

rocks; in that case they too are narrow, scarcely passable canyons, as between Siau-wang-kién and Chang-k'óu-shï; but 2 to 3 miles, 3 to 5 kilometers, south and southeast of Lung-t'an-ssï and about Mu-tzï-p'ing the valleys eroded in slate are comparatively open, though nowhere so widened as to leave space for an acre of bottom-land. There is no doubt but that softer rocks influence the grading of gentler slopes, but it is also possible that the wider valleys represent a stage of corrasion antedating that of the lower canyons, which have in that case not yet cut back into them (Fig. A, Plate XL). Thus the open valleys above 4,500 feet, 1,375 meters, southeast of Lung-t'an-ssï, may correspond to the terrace at 3,400 feet, 1,035 meters, near Ïr-ling-p'u, if the valley at that time had a fall of about 70 feet, 20 meters, to the kilometer; or to the terrace at 4,500 feet, 1,375 meters, provided the northern front of the range has been raised somewhat higher in later faulting than the district about Lung-t'an-ssï. It is possible to find among the valleys and terraces relations which correspond very nicely, but the cases are not sufficiently numerous to support an inference as to the movement of the mountain block, whether one of uniform uplift, of warping, or of rotation.

When we ascend above Ïr-ling-p'u or Lung-t'an-ssï to about 6,000 feet above sea, we find a wide ancient valley expanded between narrow-crested ridges and pyramidal hills (Fig. A, Plate XLI). Surviving spurs are numerous but narrow, and they slope from 6,500 to 5,500 feet, 1,975 to 1,675 meters; near the upper limit they pass into the steeper hillside; near the lower they end at the abrupt canyon edge. The surface is covered with residual soil, now deeply gullied in consequence of destruction of the forest for lumber during the last thirty years.

The valley high above a river is a general feature of the Ts'in-ling-shan, as may be seen from a broad view sketched from a commanding peak southwest of Siau-wang-kién (Plate XLII). It is there indicated by the profiles marked *b*, which are traceable even in the great and distant heights of the Ta-pai-shan. It is a topographic condition closely resembling that which was seen in the Wu-t'ai-shan and marked *b* on Plate XXX, and it is interpreted as corresponding with that in representing a mature stage of topography. In northern China we know it as the T'ang-hién stage of degradation, followed by the Hin-chóu stage of aggradation; but in central China we can not recognize these by their characteristic relations, and it is best to distinguish the mature stage in the southern region by a separate name. It is well represented in the ancient high valleys of the Ta-pai-shan and Ts'in-ling-shan, and we call it the Ts'in-ling stage. The character of relief appropriate to its stage of development may be seen in the higher profiles of the sketches and photographs (Plates XLI and XLII); or may

be noted here and there in atlas sheet *a* 2, in the contours of gently sloping spurs and higher ridges, above 6,000 feet, 1,200 meters. We shall see that the Ts'in-ling stage is recognizable throughout most of the mountainous region southward, to and beyond the Yang-tzï-kiang.

Summits of the Ts'in-ling-shan.—The pass of Wön-kung-miau in the main divide of the Ts'in-ling-shan is a broad gap in massive granite at an elevation of 7,640 feet, 2,328 meters. It is not so low as some other gaps and is not particularly easy to reach from the north on account of the canyon above Siau-wang-kién, but it leads to the P'u-ho by a convenient and direct route down a tributary valley. The wide summit of the range at the pass slopes gently south to a flattish basin a mile long, which was swampy at the time of spring thaws. It is aggraded and around its margin protrude residual boulders, over which the rivulets discharge in little cascades. Under appropriate conditions its form might be due to ice or wind scour. There being absolutely no evidence of glaciation in far more favorable locations than this, the accumulation of ice is improbable; on the other hand, in the absence of vegetation due to aridity, wind would be entirely competent to sweep out residual soil and saplite, leaving boulders among and over which sediment and humus would accumulate after a return of humid conditions.

From the height of the pass at Wön-kung-miau and from other commanding points we are able to look abroad over the summits of the Ts'in-ling-shan in all directions. Unlike many other passes in mountains which have been deeply dissected, this one is as high as the general level of the principal ranges, and we see that level in looking north, east, south, and west. It is represented in the nearer view and to the north by cols among the pyramidal heights, and in the more distant view, both north and south, by long descending ridges. Some 30 miles to the southwest lies the Ta-pai-shan, the snowy range which has attracted the attention of many travelers. Its altitude is from 11,000 to 12,250 feet, 3,350 to 3,735 meters, and the forms of its individual peaks are broadly pyramidal. No traces of cirques, which might be significant of glaciation, are to be seen, even in its highest valleys. It presents topographic forms essentially identical with those of the 9,600-foot, 2,925-meter mountain between Lung-t'an-ssï and Mu-tzï-p'ing, which may be seen in Fig. A, Plate XL.

Although in general upland form the northern and southern slopes of the Ts'in-ling-shan are similar, yet there are marked contrasts in other respects. North of the divide the forests have been cleared and but partly replaced by an undergrowth of shrubs and small deciduous trees. South of the divide the original coniferous forest clothes the summits and slopes, and as, late in April, we descended into the valley of the P'u-ho, we left the

Near San-ho-k'óu, Shen-si, atlas sheet a 3. View of valley of P'u-ho looking southeast from point about 150 feet above the river to mouth of the Wön-shui-ho. Terraces of previous valley levels are very distinctly shown in near bluff on the right, at the same level in the distant valley, and also at a higher level. In foreground are rice-fields.

A

B

A. Shï-ts'üan-hién, Shen-si, atlas sheet a 3. View of city on north bank of Han river, and of outcrops of Shï-ts'üan red sandstone. Valley of the Han is here much wider than it is either above or below, and the city is located at an important crossing of the river.

B. Canyon of the Han-kiang, 5 miles below Han-wang-chung, Shen-si, atlas sheet b 4. View showing development of canyon in soft phyllites; a terrace representing a former valley level about 250 feet above the river is seen in right foreground, and a much higher one in profiles in right distance.

forbidding canyons of the northern slope and the chill climate of lingering winter for sunny valleys and the aspects of spring.

Southern slope of the Ts'in-ling-shan.—Descending to Ning-k'ou-ssï, we passed waterfalls over granite ledges, and there found a very narrow glen within a stretch of sloping fields strewn with big angular rocks. For some reason, probably a line of close jointing, the gorge is narrowed for 200 meters and sunk a hundred feet in the previous valley floor, which is not so well preserved below the glen. Between Ning-k'ou-ssï and Ts'ai-kia-kuan our route lay by small brooks tributary to the P'u-ho, which show processes of recent adjustment to the belts of softer schists. We soon left the stream that flows by Ning-k'ou-ssï and entered a back valley, in which we crossed two low divides, separating little watersheds that discharged westward between hills of harder rock. In the province of the Han valley such adjustments are more conspicuous than in any other district through which we passed. The rock mosaic is generally composed of schists, which are weak, not only because of their mechanical fissility, but also because they are deeply decayed, whereas certain quartzites, limestones, and homogeneous granite masses are relatively hard. The mosaic has long been exposed to erosion, and the streams have had opportunity to reach adjustment and have to a considerable extent done so; yet in consequence of having recently sunk their channels, in some cases hundreds of feet, they have become superimposed upon newly discovered hard ledges and have developed new opportunities for readjustment along weaker zones. Thus their valleys present alternations of canyons and open stretches; yet nowhere may we look for wide bottom lands, for there has not been time for their development.

Approaching the P'u-ho above Ts'ai-kia-kuan at an elevation of 3,500 feet, 1,050 meters, we came upon the highest rice-fields, established on a broad alluvial cone; and thence southward to Shï-ts'üan-hién our way lay through a district in which small farms are numerous, both in the little strips of alluvium beside the river and on the spurs of the mountain slopes. The benches on the hillsides occur in continuity of relations such as to show that they are not accidents of relief due to hard rocks, but represent former levels at which the valley floor was temporarily developed during the process of sinking the channel. We see these benches in Plate XLIII, at no great height above the stream, and may observe that others are faintly recorded in higher slopes, but we are not able to reconstruct the details of history from our meager observations. At San-ho-k'ou and near Liang-ho there are well-developed ox-bows, which are incised 300 feet, 90 meters, below the level of the valley, in which they probably originated and which afford some measure of the latest sinking of the valley.

At Liang-ho we left the P'u-ho, which flows south by west to the Han-kiang, and crossed the hills to Shï-ts'üan-hién. In this stretch we first became distinctly aware of the deep decay which the schists of the region have suffered. In the degree of surface disintegration the saplite resembles that of the southern Appalachians in a parallel latitude, but the streams get down to hard rock in the shallower channels and it is probable that the depth of decay is not so great. The district is a hill country of moderate relief, the tops rising probably not more than a thousand feet above the valley, and the streams branch extensively in the soft surface. On the larger stream near Fan-chan-tan and Ssï-yen-pa small ox-bows wind about remnants of valley terraces which are about 150 feet, 45 meters, above the river, at points where ledges of hard quartzite form narrows in the valley.

Review of the Ts'in-ling-shan.—Considered in a broad section from north to south, the Ts'in-ling-shan is a mountain region which is high near its northern margin, slightly higher one-third of the way across it southward, and low in its southern slope. Its ridges rise from the plain of the Weï-ho in a few miles to an altitude of 7,000 feet, 2,100 meters, and maintain that elevation southward across the main divide, whence they gradually decline. It follows that along the northern margins the rivers debouch upon the plain from deep canyons, whereas the valleys of the southern slope become shallower and more open as they descend. If we regard the higher features we find that the mature surface of the Ts'in-ling stage lies high in the north, and along the northern front ends abruptly a short distance south of the fault-scarp where it is cut away by the retrogressive work of the accelerated streams. It remains elevated across the main divide, being represented in the pass at Wön-kung-miau and in all the high spurs and ridges east and west. Above it rise numerous broad pyramidal summits, which were the hills surviving at the stage of its fullest development, and which then had a relative altitude of 1,000 to 2,000 feet, 300 to 600 meters, but which now are the highest summits of this great mountain range and stand 8,000 feet, 2,400 meters, above the plain of the Weï valley. Passing over the divide, we see this Ts'in-ling surface sinking gradually until, on the lower P'u-ho and in the vicinity of Shï-ts'üan-hién, it is represented by cols and old valley levels at an elevation of about 2,500 feet, 750 meters, above sea, instead of over 7,000 feet, and the hills which diversified it probably do not rise more than 700 or 800 feet, 210 or 240 meters, higher. Thus, in the elevation of this old surface, as well as in the depths of the canyons, we find evidence that the mass of the Ts'in-ling-shan is warped, the northern portion having been raised along a normal fault, the central portion having been warped somewhat higher, and the southern less elevated or relatively depressed.

A

B

A. Three miles S. E. of P'ing-li-hién, Shen-si, atlas sheet c 5. General view up valley of P'ing-li river, showing acute profiles of mature topography. Stream is sunk in canyon whose banks present overlapping profiles which hide it; one may detect a former valley level extending from the point of view, altitude 2,700 feet, far into the distance.

B. Half a mile south of Wa-tzĭ-p'ing, Shen-si, atlas sheet d 6. View in a valley of the Sin-t'an shale, looking north to a mountain range of the Ki-sin-ling limestone. Old valley level represented in long ridge.

Seven miles southeast of Pa-kua-miau, Shen-si, atlas sheet c 5. View in aggraded upland valley above a canyon of tributary of the Nan-kiang, showing local alluvial terrace which survives at the head of a lateral canyon 300 feet above the main stream.

The development of the streams is in accordance with the slopes due to warping and the character of the rocks. The rivers tend toward courses which are consequent upon the northern and southern slopes. The smaller streams appear to be strictly consequent, but the Heï-shui-ho and the P'u-ho are both of them somewhat eccentric in that they flow diagonally, especially in their headwaters. Between them lies the great mass of granite, which forms the main range at Wön-kung-miau, and which may perhaps have been a determining factor in establishing the divide between their watersheds.

Basin of Han-chung-fu.—We did not visit the basin of Han-chung-fu, but as it is peculiar as a wide intermontane plain in a region where nearly all the valleys are canyons, the following description is quoted from von Richthofen:*

The great mountain barrier which shuts in the valley basin of Han-chung-fu on the north appears to extend in a nearly east-west direction throughout a stretch of 60 geographical miles, from Mién-hién to the east of Yang-hién; whereas the less abrupt southern rim lies in the shape of a bow. The river has been forced over to the south side of the valley, probably by the alluvial cones built out from the Ts'in-ling-shan. The valley is a deeply sunken basin. To one who has wandered through the southern and western mountains its wide level fields and graveled terraces along the base of the hills must seem like a broad and beautiful plain; whereas to one from the north, coming from the extensive plain of the Weï valley, it appears to be only a limited basin, which is nevertheless, through its wealth of waters, its mild climate, its luxuriant vegetation, and the southern aspect of the products of its fields, a paradise. The valley of Han-chung-fu is of limited extent; with a length of 60 geographical miles, the breadth appears not to exceed 12 and is generally much less, so that we may take the area of the basin at about 25 German square miles at the most.

East of Yang-hién the Han soon enters a mountainous region through which it winds in crooked course with many rapids. There the mountains of the southern side join those on the northern, a fact which we may interpret as indicating that there the folds which extend from WSW. to ENE. are cut through by the river, but not interrupted, and thus extend directly to merge into the folds of the Ts'in-ling.

* China, vol. II, p. 589. "Der gewaltige Gebirgsrand welcher das Thalbecken von Han-tschung-fu im Norden einfasst, scheint für eine Strecke von 60 g. M., von Mién-hsién bis östlich von Yang-hsién, ziemlich genau von W nach O zu verlaufen, der sanfter geformte Südrand aber eine eingebuchtete Gestalt zu haben. Der Fluss ist, wahrscheinlich durch die vom Tsin-ling-shan herabgeführten Schuttkegel, nach der Südseite des Thales gedrängt. Letzteres ist ein tief eingesenktes Becken, das mit seinem ebenen Boden und seinen sanften, an die Gebirgsränder gelehnten Schotterstufen demjenigen, der die westlich und südlich gelegenen Gebirgsländer durchwandert hat, wie eine weite, schöne Fläche erscheinen muss, während der von Norden, aus dem ebenen Boden des Wéi-Thales Kommende nur ein kleines Thalbecken sieht, aber in der reichen Bewässerung, dem milden Klima, der üppigen spontanen Vegetation und dem südlichen Charakter der dem Boden abgewonnenen Producte ein Paradies erblickt. Das Thal von Han-tshung-fu hat eine geringe Ausdehnung. Bei einer Länge von 60 g. M. scheint die Breite nicht über 12 zu betragen, meistentheils aber viel weniger, so dass wir das Areal des Beckens auf höchstens 25 deutsche Quadratmeilen ansetzen können.

"Oestlich von Yang-hsién tritt der Han bald in bergiges Land ein, durch welches er sich, reich an Stromschnellen, mit gekrümmtem Lauf windet. Dort wachsen also die Gebirge der Südseite mit denen der Nordseite zusammen, und zwar werden wir dies so zu verstehen haben, dass daselbst die von WSW nach ONO gerichteten Faltungen, von dem Fluss durchsetzt, aber nicht unterbrochen, unmittelbar fortziehen, um sich den Tsinling-Faltungen anzuschaaren."

Canyon of the Han.—From Shï-ts'üan-hién to Hing-an-fu, a distance of 105 miles, 168 kilometers, the canyon of the Han exceeds in beauty many world-famed gorges. There are stretches of the lower Danube which might compare with it, but fall far short in grandeur; in the Highlands of the Hudson there are features of massive gray crags and foliage which one sees repeated on the Han, but the vista of great mountains is lacking. The Han, a stream of great volume rarely more than 200 meters wide, flows in long quiet reaches or dashes in rapids over gravel bars and rock ledges. It is usually confined by cliffs near the water's edge, and these sometimes rise boldly to heights of a thousand feet or more, but more generally the higher slopes of the canyon are wooded or cultivated. The view is often limited to the immediate hills, but when the boat sweeps round a turn and opens a distant reach, there rise before one the forms of splendid mountains, from 4,000 to 6,000 feet, 1,200 to 1,800 meters, above the stream and impressively near.

Near Shï-ts'üan-hién there is a wide valley belonging to a small stream, which comes from the northwest. The Han enters from a canyon, and after flowing for 3 miles, 5 kilometers, in the wider valley, leaves it to strike across ledges of limestone and granite. At Lién-hua-shï (Lily Flower Rock) white surfaces of granite rise directly from dark eddies, and the canyon narrows; thence it widens and narrows alternately as the river flows through schists or limestone. Fig. B, Plate XLIV, illustrates the milder forms, and the view on atlas sheet *b* 4 a more rugged phase.

At one point only was it practicable for us to leave our boats long enough to climb to the hilltops adjacent to the river. Near Siau-tau-ho I ascended about 900 feet to a spur on the right bank. From that point the view up the Han showed an old valley level, 1,200 feet above the river, extending widely to the mountain slopes which in that vicinity rise 1,000 to 2,000 feet, 300 to 600 meters, above it. The spur on which I stood corresponded to a later valley, 300 feet, 90 meters, below the general surface, and the lowest developed on the comparatively hard slates of this section. Elsewhere, at least two stages of canyon widening had been noted at lower levels. It is probable that we may consider the higher surface as the representative of the Ts'in-ling stage, of which it has the characteristic features, and that the old valley floors at lower levels are records of intermittence in the upward movement.

Basin of Hing-an-fu.—The Han-kiang below Siau-tau-ho enters a zone of soft phyllites. The hills decline and recede from the river, and the basin of Hing-an-fu opens to the north and south. The river flows across it and leaves it on the western side to enter among the high mountains, which wall in its lower canyon.

The basin is apparently a widening of the river valley, which might readily be attributed to the softness of the sericitic schists in which it is excavated. Certainly it is probable that the weakness of the rock has promoted the widening, but it hardly seems to suffice to explain all the facts, as the same schists form the hills where we crossed them on the southwest. The direction of the longer axis, which is nearly at right angles to the course of the river, the gentle slopes which sink toward the basin, and its peculiar situation among high ranges suggest that it is an oval downwarp modified by erosion.

The river flows across it in a gravelly channel above bed-rock, and is faced on the north opposite the city by bluffs of gravel about 120 feet high, to a level surface. The southern margin of this deposit, which occupies a large area in the basin and which once undoubtedly filled it, at least to the top of the bluff, was crossed near the 1,100-foot contour 3 miles, 5 kilometers, southeast of the city. The deposit consists of river gravel and shingle, with pebbles up to 15 inches, 38 centimeters, in diameter and occasional beds of sand. The stratification is essentially horizontal and the strata are cross-stratified in various directions. The pebbles represent all the varieties of schist, argillite, quartzite, granite, and basic intrusives, which we observed along the Han. All those rocks which are liable to decay are thoroughly decomposed, only quartzite and siliceous argillite remaining sound. The pick was easily driven through the largest granite cobble. Thus it seems probable that the deposits are not of the latest Pleistocene age, but older. We call this deposit the Hing-an gravels.

In the valley southeast of Hing-an-fu we found a rock-cut terrace at the 1,100-foot contour, corresponding with the upper limit of the Hing-an gravels. Thus it is apparent that some condition determined lateral corrasion by the stream when at that level, and the suggestion lies near that the gravels accumulated as delta deposits in a body of water confined among the hills. In the light of present knowledge it is equally possible that the surface of the gravel deposit formed for a time the local base-level to which the streams cut.

From the Han to the Nan-kiang, southeast of Huang-yang-p'u, our route followed the valley of a brook in a little canyon 80 to 120 feet deep which wound about so constantly that the view was limited to a hundred yards or so ahead. Each of the little bends partially inclosed a remnant of the valley floor on which the brook had assumed its meandering course and which correspond to the surface of the Hing-an gravel.

On ascending to the ridge above Lau-hién, at an altitude of 2,200 feet, 670 meters, above sea, we looked northward over the old valley surface, which had been recognized in the view of the Han valley near Siau-tau-ho.

It slopes gently northward and about the Hing-an basin is represented by the hilltops which approximate 1,900 to 2,000 feet, 580 to 600 meters. Many hills rise above it, some of them reaching altitudes of 3,500 feet, 1,075 meters. They present pyramidal and sometimes angular forms, characteristic of the residual heights between watersheds established in essentially homogeneous and rather soft rock, such as the schist is. In crossing the divide to Liu-wang-miau, we traversed part of a ridge approximately 3,000 feet, 900 meters, above sea, which seemed to have that correspondence with adjacent ridges which might suggest a remnant of a higher and older surface.

Descending to Ling-kuan-tién, we reach the valley of a river which, lacking the native name, we will call the P'ing-li river after P'ing-li-hién. It is a clear swift stream 50 meters across, which frequently breaks over gravel bars, where it may be forded on foot. The valley exhibits those features of partial adjustment which were noted on the upper P'u-ho, there being stretches where the main stream cuts across hard rocks and little parallel valleys are being opened on softer belts. Such an instance occurs just south of Ling-kuan-tién, where the trail leaves the river and returns to it a mile and a half further up. Proceeding upstream toward P'ing-li-hién, the valley widens, and from the coal-mines a mile and a half above the city it extends as a broad open channel southeastward. It is said to continue in that general direction across a low divide about 30 miles, 50 kilometers, to Chu-ki-hién, in the valley of the eastward flowing Nan-kiang. A small brook now occupies the open river valley into which the P'ing-li river flows with a northeasterly course, opposed to that which it takes after entering the valley. The relations of the abandoned valley and its tributary are such as to indicate that formerly a river flowed southeastward past the coal-mines, probably to join the Nan-kiang at Chu-ki-hién. That stream has been checked by warping, which reversed the slope of its bed and afforded opportunity for its diversion to the present northerly course beyond Ling-kuan-tién. The sluggish stage of the old river, prior to its diversion but subsequent to the beginning of the warping, is apparently represented near P'ing-li by 10 or 15 feet, 3 or 4 meters, of gravel capping a terrace about 40 feet, 12 meters, high, the lower part of which is a recent rock cut.

South of P'ing-li-hién the route avoids the canyon for a few miles, and after a sharp ascent follows for some distance the surface of the old valley level which is here at an elevation of 2,700 feet, 825 meters, above sea (Fig. A, Plate XLV). At Pa-li-kuan we again descend to the river and meander beside it to Pa-kua-miau. It runs in an exceedingly picturesque and fertile valley, with little stretches of bottom-land cultivated as rice-

A

B

A. Pass of Ki-sin-ling, atlas sheet d 6, the junction point of three provinces, Shen-si, Hu-peï and Ssï-ch'uan. View eastward up headwaters of the Nan-kiang, in synclinal valley on Sin-t'an shale overlying Ki-sin-ling limestone. The stream in this valley formerly flowed to the right and was tributary to the Yang-tzï by way of the Ta-ning-ho; it now turns to the left of the view and passes through the limestone wall in the gorge shown in Plate XLVIII.

B. Two miles north of Pa-ho, Ssï-ch'uan, atlas sheet d 7. View up canyon of Ta-ning-ho, showing the characteristic cliffs of Wu-shan limestone surmounted by older topographic forms. Terraces high above the river in the distance probably represent a level at which the river widened its valley, but may be occasioned by ledges of limestone overlaid by softer strata.

One and a half miles south of Wa-tzï-p'ing, Shen-si, atlas sheet d 6. View of the gorge through which the Nan-kiang has extended its head waters and captured the former tributary of the Yang-tzï shown in A, Plate XLVII.

fields, and hillsides on which grow large and handsome trees, ever closing in the vista of the winding stream (Fig. B, Plate III).

Between Pa-kua-miau and Pai-kiu-hia (atlas sheets *c* 5 and *d* 5) we crossed two divides, the northern 4 miles, 6.5 kilometers, southeast of Pa-kua-miau at an altitude of 5,000 feet, 1,500 meters, and the southern at Hung-kia-ying at 4,100 feet, 1,230 meters, above sea. Though we had thus reached an altitude of 4,000 feet, 1,200 meters, above the Han river at Hing-an-fu we were still within its watershed, and descended to the canyon of the Nan-kiang, whose course is first easterly and then northeasterly past Chü-shan-hién to a junction with the Han above Yün-yang-fu.

Up the Nan-kiang.—In distant views which we had of the valley of the Nan-kiang, we observed the elements of topography which we had recognized elsewhere in the region, but they are developed on a grander scale. The Nan-kiang flows in a narrow and often impressive canyon, between cliffs which are frequently 500 feet, 150 meters, in height, and which descend abruptly into the river, forcing the trail to cross, or where that is not practicable, obliging the natives to cut the pathway in rock. At several points such work has been done to make the route practicable.

Two miles, 3 kilometers, north of Ku-niu-tu (atlas sheet *d* 6) there is an interesting occurrence of a stream which enters the main river from the west in the middle of the concave side of an ox-bow, between two high sharp-crested ridges. The peculiar relations of the tributary and the bend suggest that the ox-bow was caused by the alluvial cone of the small stream, at a time when the valley was 300 feet, 90 meters, above the present channel, and that the tributary now pursues the course which it took on its alluvial cone. The feature is significant of a gentler fall of the main river than that which it now has, for at the present time its powerful current sweeps away the gravel contributed to it, even by much larger streams than the little brook that now enters the ox-bow. This old valley level of the Nan-kiang, clearly developed 300 to 500 feet, 90 to 150 meters, above the river (Plate XLVI), has a relation to the inner canyon parallel with that of the elevated valleys we saw south of Hing-an-fu about 120 feet, 36 meters, above the streams in that region. The canyon of the Nan-kiang is cut deeper, because the stream is higher above its level of discharge and is a far more powerful river. It is still cutting vertically, its channel being high above a graded profile.

As the canyon became deeper and walled us in more closely (Plate IX), we saw less and less of the nearby heights, yet we were conscious, from glimpses of distant peaks, that we were entering among much higher mountains than those we had traversed. Four miles south of Chön-p'ing-hién we emerged into an east-west valley developed on a zone of soft shales,

and saw the main divide rising like a castellated wall of limestone before us (Plate X). Our elevation was about 3,400 feet, 1,050 meters, and that of the summit 7,000 to 8,000 feet, 2,100 to 2,400 meters. The crest was but 3 miles, 5 kilometers, away and the nearly vertical limestone strata formed sheer mural precipices. The approach to the pass was through a remarkable gorge south of Wa-tzï-p'ing. The open valley in the soft shales narrows to a slit between the limestone precipices, which are but 6 to 10 feet, 2 to 3 meters, apart for a distance of a hundred meters (Plate XLVII). Then the mountain gorge widens slightly and the trail ascends over benches and around cliffs, a thousand feet to the pass. The view eastward from the summit is up a broad valley (Fig. A, Plate XLVIII) very unlike the profound gorge from which we have climbed, and the dip plane of the limestone forms the bold southern slope of the main range. But the stream, still taking its course to the Nan-kiang, flows directly into the limestone mountains, through a gate still narrower than that lower one through which we ascended, and cascades down to Wa-tzï-p'ing. The trail, having passed the point at which the three provinces of Ssï-ch'uan, Shen-si, and Hu-peï corner, follows a level ridge for half a mile toward the southwest, and then descends the steep slope of the watershed of the Yang-tzï-kiang. A study of the old valley profiles shows that the headwaters formerly followed a well-adjusted course along the belt of soft shales, and flowed to the Yang-tzï. This former course of the stream is represented by a col having an elevation of 5,200 feet, 1,585 meters, above sea and 600 feet, 180 meters, above the present valley. It is evident that the original stream was retarded by warping and, being reached by an energetic branch of the Nan-kiang, was diverted to the northward course in spite of the fact that the local conditions were unfavorable to diversion. The attacking rivulet had to cross a limestone ridge at least a mile broad, and the stream which was attacked possessed a sufficient watershed to give it great advantage in volume. Furthermore, it was flowing upon soft shales which had formerly determined the adjustment of its course. That, under these conditions, the diversion should nevertheless have been accomplished is evidence that the northward declivity resulting from warping was very considerable.

Watershed of the Yang-tzï-kiang.—From the Ki-sin-ling pass at an altitude of 5,500 feet, 1,675 meters, we descended in 4.5 miles, 7 kilometers, to the Ta-ning-ho, only 1,600 feet, 480 meters, above sea, the path following a little lateral stream, which at its lower end leaps 1,200 feet, 360 meters, in a very short distance (Plate XLIX). The point which we thus reached on the Ta-ning-ho is Tung-kuan-k'ou, and the fall of the river in a course of about 70 miles, 110 kilometers, to Wu-shan-hién is approximately

Ta-miau-ssï, Ssï-ch'uan, atlas sheet d 6. View from point about a mile south looking across the Ta-ning-ho at Tung-kuan-k'ön. In foreground are slopes of Sin-t'an shale. Cols and summits 1,500 to 2,000 feet above the river probably represent old stage of the valley. Gorge 1,200 feet deep leads down through the Wu-shan limestone to the river, beyond which rises a peak of the same formation. The mountain behind consists of earlier Paleozoic rocks overthrust upon the Wu-shan.

1,400 feet, 420 meters, or about 20 feet, 6 meters, to the mile. There are long stretches with scarcely perceptible current (Fig. B, Plate XLVIII), rapids over shallow gravel bars, and occasional falls of a few feet over the edge of a limestone stratum into a basin in soft shale below. The stream is, however, navigable for boats which resemble Venetian gondolas, and which, being both light and well-modeled, are safely guided through the rapids by skilful boatmen or tracked up by means of tow lines. The commerce on the river, especially in coal, which is mined at T'an-mu-shu-p'ing, and in rice and goods, which are used in the mountains, is considerable.

Our route was unfavorable for physiographic study, the limestone precipices shutting us in so closely that even distant views of the adjacent heights were rare (Plate LI). We saw, perhaps, a seemingly individual mountain form several thousand feet above us in the distance; approached it, passed beneath it, and turning from some further point found that we could no longer identify it among many similar crags. Hence it was difficult for Sargent to even sketch the most prominent of the cliff tops next the canyon, and greater eminences a little back from its margin escaped us altogether.

At certain points, however, we obtained wider views, as between San-shï-li-p'u and Kiu-shï-li-p'u, where the valley widens in the red beds. We were then able to recognize the types of topography which we had seen in crossing the Ki-sin-ling, and to observe that the mountain ranges are but little lower near the Yang-tzï than they are on the main divide. Thus the canyons become deeper as we proceed downstream, and two of the narrowest and most beautiful occur just above and below Pa-ho. The fall of the river increases as we approach the Yang-tzï-kiang, and several of the heaviest rapids occur in the canyon two miles north of Wu-shan-hién.

The course of the Ta-ning-ho is nearly at right angles to the structure of the region, except in the red valley between San-shï-li-p'u and Kiu-shï-li-p'u. Nearly all of the smaller streams have developed in belts of shale, whereas the great mountain ridges are outcrops of limestone. The limestone has often been stripped, exposing long dip slopes, and the mountain is a more or less perfect anticlinal arch. It is evident that the course of the Ta-ning-ho, across very pronounced folds and in spite of very marked differences among the rocks, is not one which could have been acquired under existing conditions of relief. The stream could only have originated upon a surface not far below the summits of the present mountains, and on a slope which sufficed to give every advantage to brooks that flowed southward. It probably developed by the growth of such brooks, which, being accelerated, were enabled to divert to their transverse course any streams flowing on the strike of the rocks.

Gorges of the Yang-tzï-kiang.—The gorges of the Yang-tzï-kiang have been too well described to require any statement in this place of their superb grandeur and imposing magnitude. Views on the Yang-tzï are more extended than those on the Ta-ning-ho, the canyon being several times as wide, and the relations of the different elements of the topography are more clearly observable. The bluffs and cliffs which bound the river vary greatly in altitude, according to the nature of the rocks, and in the red beds there are evidences of valley widening of which there is no trace in the limestones. It is evident that the powerful current of the Yang-tzï, one of the most efficient corrading engines of the world, has been able to expand the valley in these softer rocks repeatedly, while it was still sawing vertically in the harder ones. It is therefore in the red beds that we should look for the minor evidences of the river's activity, since only the major ones are recorded in the limestone. But we could make no attempt in passing to note more than a greater widening of the valley, at an elevation of perhaps 600 feet, 180 meters, above the channel, than any which had occurred at the lower level. This episode is clearly marked in the area of the Huang-yang granite, which is now an extensive hill country of corresponding relief.

The cliffs which wall the Yang-tzï gorges are sometimes sheer for 2,000 feet, 600 meters, as estimated in passing. Above that altitude they recede in a decided bench, above which the mountains rise 2,000 to 3,000 feet, 600 to 900 meters, higher. It is probable that the level 3,000 feet, 900 meters, above the river is the floor of the valley, which was occupied for some length of time prior to the last sinking of the canyon. Since the pause at that stage permitted the widening of the valley on the harder rocks, there was no doubt a far more extensive broadening upon the red beds and granite, but the valley floor on those rocks has been lowered many hundred feet, at least near the river, and the higher level, if it still survives on them, is to be seen only in the foothills of the adjoining mountains.

The Yang-tzï is not only the master stream of the province, but one of the great master streams of the world. If we therefore infer that it is an ancient watercourse, which originated on the fluted surface when the red beds and Paleozoic strata were folded, we might expect that it would flow as far as possible in synclinal valleys, and would leave them only where adjacent anticlines are low. Its channel is indeed to some extent adjusted to the red beds, which are at once the softest and youngest rocks of the region; it appears to flow in a synclinal valley of this kind above K'ui-chóu-fu; it takes a similar course above Wu-shan-hién and again near K'ui-chóu-hién, Hu-peï. In certain other instances the river, having cut through the Carboniferous limestone, flows for some distance in a synclinal

One mile south of Sü-kia-pa, Ssï-ch'uan, atlas sheet d 6. View in the canyon of the Ta-ning-ho, cut across an anticline of the massive Ki-sin-ling limestone.

Three and a half miles below Ta-ning-hièn, Ssï-ch'uan, atlas sheet d 6. View of canyon of Ta-ning-ho in deepest part of gorge cut by the stream across anticlinal arch of Wu-shan limestone, showing narrow character of inner canyon and higher benches developed according to levels of hard and soft strata in the limestone.

valley in Cambro-Ordovician, and it is evident that such stretches were originally determined above the Carboniferous on the red beds, whose position would now be between 4,000 and 5,000 feet, 1,200 and 1,500 meters, above water. But the various stretches of the river are not even approximately axial along synclines, and they alternate with other sections across and along anticlines, sections which are not adjusted to structural conditions. Hence we are led to infer that the present course of the Yang-tzï is not one which was taken upon a fluted surface due to folding, but may be either a derivative from such an original course or else one which has developed by the growth of a smaller but dominant river, that by a succession of captures succeeded in uniting many watersheds. The record of such derivation or development is not to be seen from the river. The Yang-tzï is imprisoned by tremendous canyon walls, which its own flood has carved and is still carving. Whatever channel it once had other than that which it is deepening, may be traced only above the great cliffs among the mountain summits.

In deepening its channel, the Yang-tzï has lowered the level of discharge of its tributaries, and so has promoted their growth in competition with the tributaries of the Han. The divide of the Kiu-lung-shan should be the direct resultant, but is not. The Ta-ning-ho has a much shorter course and steeper fall than the Nan-kiang, a tributary of the Han, and about its headwaters is favored by an area of shale, in which it once developed the wide valley of the Ki-sin-ling; nevertheless it has lost that valley to the Nan-kiang, a loss which, as we have already noticed, could only have been occasioned by strong warping. The axis of maximum upwarp appears to lie not far south of the Ki-sin-ling, and the descent from it toward the Yang-tzï is apparently one of about 2,000 feet, 600 meters, in 50 miles, 80 kilometers. It is on this slope that the Ta-ning-ho and other southward flowing tributaries took their course, directly across the structural lines of the region. The fact that we do not find any great longitudinal valleys between the crest of the Kiu-lung-shan and the Yang-tzï would seem to indicate that this condition was a general one, and that the older drainage, whatever its courses may have been, was completely dissected and diverted.

Where we pass from the I-chang gorge eastward beyond the mountains, the surface sinks gradually toward the flood-plain of the Yang-tzï and the strata dip gently beneath it. The long slope is margined by foothills of red beds and higher up corresponds over large areas with the dip plane of the Carboniferous limestones. Though sometimes described in terms of exaggeration as of wall-like steepness by which a fault-scarp is suggested, it is a warped topographic surface, an eastern slope of the broad upwarp

of the Kiu-lung-shan. That such a warp should locally give way to a fault-scarp would be consistent with the relations of warped surfaces and faults, as we observed them through northern China; but at I-chang the slope is not broken.

PHYSIOGRAPHIC STAGES.

In the course of our journey of 350 miles, 560 kilometers, from the Weï valley across the Ts'in-ling-shan, down the canyon of the Han, and across the Kiu-lung-shan to the Yang-tzï, we observed evidences of but two physiographic stages: the one, which is characterized by a mature topography of notable relief, we have called the Ts'in-ling stage; the other, whose characteristic form is the canyon, we might designate the Fön-ho stage, applying the name used in North China; but in view of the differences of conditions in the north and south, it will be well to distinguish the southern type from the northern by giving it another name, and none could be more appropriate than that of the Yang-tzï stage.

TS'IN-LING STAGE.

The Ts'in-ling stage takes its name from the highest portion of the Ts'in-ling-shan. It is characteristically developed among the summits of that range, where it is represented by valleys that widen above the present canyons of the streams and wind among hills which rise 1,000 to 2,000 feet, 300 to 600 meters, higher. It was traced from these high altitudes down the southern slope of the Ts'in-ling-shan to the valley of the Han, where the elevation of its ancient valleys is probably not far from 1,500 feet, 450 meters, above sea, and the hills that diversified it rise less than a thousand feet higher. It was seen again from the spur above Siau-tau-ho on the Han river, and above Lau-hién. South of the basin of Hing-an-fu its valley surfaces range from about 1,900 feet, 580 meters, near the southern margin of the basin to 2,200 feet, 670 meters, south of Lau-hién, and the hills rise to 3,500 feet, 1,050 meters. Southward from P'ing-li views of distant ranges clearly express the elements of the Ts'ing-ling surface, namely, the long, nearly level profile of its valleys and the pyramidal sharp-pointed forms of its hills, and by these features it was followed to the Ki-sin-ling, where the valley altitude is something over 5,200 feet, 1,580 meters, and the neighboring mountains rise 3,000 feet, 900 meters, higher.

Throughout the area from the northern Ts'in-ling-shan to the pass of the Ki-sin-ling, the rocks upon which the surface is carved are essentially similar in that they are prevailingly schistose. Southward from the Ki-sin-ling, however, the folded limestones and shales of the Paleozoic present a different mosaic and the topographic type differs accordingly. The

region is characterized by mountainous ridges of limestone, which are more or less deeply eroded anticlines. Their arched surfaces formerly rose to greater altitudes than now, and in some places much higher than in others, but at present the outcropping strata maintain a somewhat uniform height although cut into precipitous peaks of extremely rugged form. Having traced the Ts'in-ling surface southward to the altitude of the Ki-sin-ling pass and finding it there essentially coincident with the summits of these dissected ridges, we recognized that they represent it. As they consist of the harder rocks, which are associated with very much softer strata, we may infer that they are the hills from about which the valley levels have been extensively eroded in the process of deeper denudation.

Apart from its own characteristic topographic type the Ts'in-ling stage may be recognized by its relation to the very characteristic and widespread form of the Yang-tzï stage, the canyons in which all streams of the province are more or less deeply sunk.

THE YANG-TZÏ STAGE.

The canyon, which is the characteristic feature of the Yang-tzï stage, is widely developed throughout the entire mountain province south of latitude 34°. Every stream is sunk in a narrow steep-banked or steep-walled channel, which may be 100 or 4,000 feet, 30 or 1,200 meters, deep. This character has been so often referred to in the preceding pages as to require no further description. As an almost universal characteristic, it stamps the entire province as one which has been elevated in later geologic time, and it is this fact of mountain growth which marks the Yang-tzï epoch. In general terms it may be said to have resulted in two great upwarps, of which the northern has developed the Ts'in-ling-shan, between latitudes 33° and 34° and east of longitude 105°; and the southern has resulted in the Kiu-lung-shan, which appears to trend from northeast to southwest, extending from the lower Han valley to the upper Yang-tzï, from about latitude 32°, longitude 112°, toward latitude 28°, longitude 107°, and beyond. Between the two is a downwarp which is occupied by the watershed of the Han, but there are very decided differences of elevation, due apparently to local upwarps and downwarps of strongly accented character. These are prominent and modify the relief of the broader general downwarp in a manner to obscure its character, by introducing high ranges.

The study of the rivers shows that, with reference to the warps of the Yang-tzï stage, they are in part antecedent and in part consequent. Among the former we may probably place the Heï-shui-ho and possibly the upper P'u-ho, on account of their diagonal courses and adjustment to the divide on the granite mass of the central Ts'in-ling-shan; and we

may certainly name the Han-kiang and Yang-tzï-kiang as antecedent. Among the consequent streams we would place all those tributaries of the Heï-shui-ho and the Weï-ho, of the Han and of the Yang-tzï, which flow in essentially parallel courses across the structure and down the warped surfaces.

We must note, however, that in all of these tributary valleys, even to the highest part of the Ts'in-ling-shan and the Kiu-lung-shan, we were able to trace the features of old valley levels which, in general, coincide in course with the existing canyons. Hence it is evident that these consequent streams developed their present lines of flow at an early stage of warping, and that their work during the Yang-tzï epoch has been chiefly in sinking their canyons without having greatly modified their drainage basins, so far as we have been able to observe. The capture which has been accomplished by the Nan-kiang at the Ki-sin-ling is apparently an exceptional instance.

CORRELATION OF PHYSIOGRAPHIC STAGES.

The distinctive names which are here given to physiographic stages recognized in northern China and in the south central provinces are but convenient terms which designate parallel sequences of events. It would, perhaps, be simpler to adopt one name to cover each of the epochs which may be recognized as common to both regions, but in so doing we should force a correlation which can not be made with precision, at least not until the physiographic study shall have been carried out on many lines of observation instead of along one route only. It seems appropriate, however, to suggest such correlation as the present knowledge indicates.

The Peï-t'ai stage of North China was clearly recognized only in the Wu-t'ai-shan, in a limited area, where it is identified by characteristic topographic features and by the occurrence of residual soil which in that district is unusual. The survival of features of such antiquity is rarely general, and, in view of the development of later physiographic phases, was not expected. It is therefore natural that surfaces of that ancient stage should not have been discovered in the southern provinces.

In North China the succeeding T'ang-hién stage was a time of development to a condition of advanced maturity, when valleys became very wide and hills relatively low and isolated; it was interrupted by the Hin-chóu stage of aggradation which resulted in the wide-spread Huang-t'u formation, and the Fön-ho epoch of mountain growth followed.

To correlate the two stages recognized in Central China with those just enumerated, it is best to reason from the later back to the earlier.

In North China as in Central the latest epoch is one of very pronounced mountain growth. Its characteristic topographic form is the canyon, and

there is between the gorges of the Yang-tzï and those of the Hu-t'o-ho in similar limestone no such difference of development as would justify us in assigning to the one feature or the other a notably longer existence. Without committing ourselves as to the relative age of one local uplift or another, we may say, with confidence, that the great ranges of Chï-li, Shan-si, and Shen-si all belong to a common time of mountain growth. The epochs which preceded them are, in North China, the Hin-chóu and the preceding T'ang-hién, and in Central China the Ts'in-ling. The last named covers the Hin-chóu and extends back into T'ang-hién time, in all probability; but inasmuch as the features of the Ts'in-ling surface are less mature than those of the T'ang-hién, it is not probable that the two overlapped during any great part of their history, provided the rates of erosion in the two districts have been even approximately the same. The Ts'in-ling epoch was initiated by warping apparently when the T'ang-hién was well advanced, and in Central China degradation has since been continuous, while in parts of North China it was interrupted during the Hin-chóu epoch.

Thus, stating the relations of the epochs in the order of development we may say: The Ts'in-ling stage of Central China corresponds in duration with the later part of the T'ang-hién and the entire Hin-chóu epoch of North China; the Yang-tzï and Fön-ho stages have been essentiallv contemporaneous.

By reference to the discussion of geologic dates of the several stages of physiographic history of Northwestern China at the end of Chapter XI, it will be seen that the correlation reached in the last paragraph places the Ts'in-ling stage in the late Tertiary and the Yang-tzï epoch chiefly in the Quaternary.

APPENDIX

TOPOGRAPHIC DATA

Table of Altitudes Determined between Pau-ting-fu, Chi-lï, and T'ai-yüan-fu, Shan-si, by Graphic Triangulation and Vertical Angles.

Description of point of which the altitude was determined.	Adjusted altitude.		Elevation obtained.	Distance, miles.	By foresight from or backsight to stations named below.
	Meters.	Feet.			
Depot at Pau-ting-fu (*datum*)..............	20	66			
Small pagoda hill 1¼ miles south of Chuang-li. Atlas sheet G 1. (Elevation of this point was found by leveling-alidade and reading and computing as in Y-level work.)	85	282			
East end base-line on NW. corner of wall at T'ang-hién. Atlas sheet G 1.	66	209*			
Station I.—Mountain north of T'ang-hién. Lat. 38° 46′ 46″, Long. 115° 0′ 18″. The elevations of East Base and Station I were obtained from the best adjustment of shots to Pagoda and fore and backsights between stations.	384	1261			
Station II.—Lat. 38° 44′ 4″, Long. 114° 55′ 40″. Atlas sheet F 1.	156	511†	508 517 511 516	7.84 5.18 2.94	Pagoda. St. I. East Base.
Station III.—On sharp-pointed hill on which is small stone hut. Lat. 38° 45′ 1″, Long. 114° 53′ 20″. Atlas sheet F 1, top of hut.	462	1515	1511 1515 1515 1518 1515 1521 1515	6.50 5.08 2.42 9.53	St. I. East Base. St. II. Pagoda.
Station IV.—Lat. 38° 46′ 40″, Long. 114° 50′ 48″. Atlas sheet F 1.	356	1167	1164 1167 1172	8.50 2.87	St. I. St. III.
I–2. A prominent point to the west. Not occupied. Lat. 38° 43′ 18″, Long. 114° 52′ 0″. Atlas sheet F 1.	334	1096	1086 1097 1109 1092 1094	8.46 6.36 3.44 2.44 3.98	St. I. East Base. St. II. St. III. St. IV.
Station V.—Lat. 38° 44′ 12″, Long. 114° 49′ 6″. Atlas sheet F 1.	223	731	728 733 731 718	3.07 4.10 3.08	I–2. St. III. St. IV.
Station VI.—Lat. 38° 43′ 24″, Long. 114° 46′ 34″. Atlas sheet F 1.	281	923	922 918 927 927	4.83 6.38 5.31 2.36	I–2. St. III. St. IV. St. V.
Station VII.—Lat. 38° 47′ 6″, Long. 114° 45′ 56″. Atlas sheet F 1.	396	1300	1296 1297 1298 1309 1305	7.02 7.10 4.46 4.10 4.30	I–2. St. III. St. IV. St. V. St. VI.
Station VIII.—Lat. 38° 45′ 32″, Long. 114° 41′ 18″. Atlas sheet F 1.	375	1232	1234 1225 1236	9.95 8.64 4.49	I–2. St. IV. St. VII.
Station IX.—Lat. 38° 49′ 2″, Long. 114° 40′ 22″. Atlas sheet F 1.	602	1975	1979 1975 1961 1977	5.72 4.34	St. VII. St. VIII.

* This and all following elevations were determined by vertical angles and known distances.

† The adjusted altitude is the mean of the separate determinations as ascertained by weighting each of them for conditions of distance, wind, etc., noted at the time of observing.

TABLE OF ALTITUDES DETERMINED BETWEEN PAU-TING-FU, CHĬ-LI, AND T'AI-YAN-FU, SHAN-SI, BY GRAPHIC TRIANGULATION AND VERTICAL ANGLES.—Continued.

Description of point of which the altitude was determined.	Adjusted altitude.		Elevation obtained.	Distance, miles.	By foresight from or backsight to stations named below.
	Meters.	Feet.			
Station X.—Lat. 38° 46′ 36″, Long. 114° 35′ 10″. Atlas sheet F 1.	572	1876	1865	7.60	St. VI.
			1879	9.66	St. VII.
			1886	5.66	St. VIII.
			1871 1872	5.38	St. IX.
Station XI.—Lat. 38° 42′ 30″, Long. 114° 36′ 36″. Atlas sheet F 1	492	1614	1623	11.30	St. V.
			1611	9.09	St. VI.
			1622 1609	8.35	St. IX.
			1624	4.89	St. X.
Station XII.—Lat. 38° 43′ 0″, Long. 114° 31′ 46″. Atlas sheet F 1.	333	1092	1097	10.30	St. IX.
			1105 1084	5.16	St. X.
			1092	4.40	St. XI.
Station XIII.—Lat. 38°, 42′ 26″, Long. 114° 30′ 34″. Atlas sheet F 1.	367	1204	1207	6.34	St. X.
			1211	5.42	St. XI.
			1195 1203	1.26	St. XII.
Station XIV.—Lat. 38° 44′ 58″, Long. 114° 25′ 38″. Atlas sheet E 1.	340	1116	1113	10.18	St. XI.
			1124 1116	5.85	St. XII.
			1114	5.13	St. XIII.
Station XV.—Lat. 38° 47′ 0″, Long. 114° 26′ 50″. Atlas sheet E 1.	384	1261	1237	6.17	St. XIII.
			1266	2.88	St. XIV.
Station XVI.—Lat. 38° 48′ 56″, Long. 114° 24′ 46″. Atlas sheet E 1.	477	1565	1543	13.82	St. IX.
			1569	9.70	St. X.
			1570 1561	9.05	St. XIII.
			1558 1556	4.92	St. XIV.
			1566	2.88	St. XV.
Station XVII.—Lat. 38° 47′ 16″, Long. 114° 21′ 58″. Atlas sheet E 1.	421	1383	1324 1365	10.04	St. XII.
			1389	9.04	St. XIII.
			1362 1391	4.42	St. XIV.
			1383	4.38	St. XV.
			1389 1389	3.18	St. XVI.
Station XVIII.—Lat. 38° 50′ 22″, Long. 114° 18′ 31″. Atlas sheet E 1.	524	1720	1722	9.12	St. XIV.
			1730 1708	5.88	St. XVI.
			1718 1722	4.72	St. XVII.
Station XIX.—Lat. 38° 50′ 35″, Long. 114° 13′ 32″.	547	1794	1769	17.94	St. XIII.
			1804	12.82	St. XIV.
			1828 1772	10.32	St. XVI.
			1794 1794	8.50	St. XVII.
			1794 1779	4.51	St. XVIII.
Station XX.—Lat. 38° 48′ 44″, Long. 114° 9′ 37″. Atlas sheet E 1.	717	2350	2354 2333	8.25	St. XVIII.
			2319 2354	4.12	St. XIX.

TABLE OF ALTITUDES DETERMINED BETWEEN PAU-TING-FU, CHÏ-LI, AND T'AI-YÜAN-FU, SHAN-SI, BY GRAPHIC TRIANGULATION AND VERTICAL ANGLES.—Continued.

Description of point of which the altitude was determined.	Adjusted altitude.		Elevation obtained.	Distance, miles.	By foresight from or backsight to stations named below.
	Meters.	Feet.			
Station XXI.—Lat. 38° 53′ 18″, Long. 114° 6′ 4″. Atlas sheet E 1.	1067	3500	3451 / 3520	11.67	St. XVIII.
			3482 / 3496	7.37	St. XIX.
			3504 / 3506	6.14	St. XX.
Station XXII.—Lat. 38° 52′ 56″, Long. 114° 3′ 45″. Atlas sheet E 1.	963	3159	3107 / 3170	9.17	St. XIX.
			3147	7.11	St. XX.
			3106	2.16	St. XXI.
Station XXIII.—Lat. 38° 50′ 15″, Long. 114° 6′ 22″. Atlas sheet E 1.	1215	3987	4105 / 3975	8.23	St. XIX.
			3985 / 3986	5.03	St. XX.
			3996	3.81	St. XXI.
Station XXIV.—Lat. 38° 54′ 54″, Long. 113° 59′ 59″. Atlas sheet D 1.	1243	4078	4073	11.27	St. XX.
			4084	5.90	St. XXI.
			4078	6.56	St. XXIII.
Station XXV.—Lat. 38° 51′ 42″, Long. 113° 52′ 30″. Atlas sheet D 1.	1679	5507	5496	12.37	St. XXI.
			5510	10.81	St. XXIII.
			5515	7.50	St. XXIV.
Station XXVI.—Watch tower on south branch of the Great Wall. Lat. 38° 55′ 33″, Long. 113° 47′ 20″. Atlas sheet D 1.	1784	5854	5849	17.05	St. XXI
			5873	16.48	St. XXIII.
			5832	11.25	St. XXIV.
			5861	6.38	St. XXV.
Station XXVII.—Lat. 38° 55′ 16″, Long. 113° 49′ 4″. Atlas sheet D 1.	1348	4422	4422	5.06	St. XXV.
Station XXVIII.—Lat. 38° 52′ 22″, Long. 113° 47′ 31″. Atlas sheet D 1.	1786	5860	5850	11.42	St. XXIV.
			5860	4.53	St. XXV.
			5870	3.65	St. XXVI.
Station XXIX.—Lat. 38° 54′ 2″, Long. 113° 41′ 4″. Atlas sheet D 1.	1839	6033	6022	10.56	St. XXV.
			6045	5.89	St. XXVI.
			6049	6.06	St. XXVIII.
Station XXX.—Lat. 38° 52′ 35″, Long. 113° 42′ 48″. Atlas sheet D 1.	1576	5170	5145	5.28	St. XXVI.
			5180	2.23	St. XXIX.
Station XXXI.—Lat. 38° 49′ 47″, Long. 113° 40′ 10″. Atlas sheet D 1.	2150	7055	7061	18.61	St. XXIV.
			7063	9.23	St. XXVI.
			7062 / 7043	7.25	St. XXVIII.
			7039 / 7063	4.87	St. XXIX.
Station XXXII.—Lat. 38° 56′ 55″, Long. 113° 37′ 28″. Atlas sheet D 1.	2255	7399	7395	10.43	St. XXVIII.
			7394	4.69	St. XXIX.
			7408	9.52	St. XXXI.
Station XXXIII.—Nan-t'ai. Lat. 38° 55′ 5″, Long. 113° 33′ 6″. Atlas sheet D 1.	2477	8129	8101	17.86	St. XXV.
			8129	13.33	St. XXVIII.
			8149 / 8111	7.30	St. XXIX.
			8115 / 8091	8.80	St. XXXI.
			8153	4.45	St. XXXII.
Station XXXIV.—Lat. 39° 0′ 38″, Long. 113° 38′ 11″. Atlas sheet, D 1.	2261	7419	7441 / 7398	7.83	St. XXXIII.
Station XXXV.—Lat. 39° 0′ 26″, Long. 113° 37′ 47″. Atlas sheet D 1.	2233	7328	7310	7.31	St. XXXIII.
			7319	.45	St. XXXIV.
			7342	.66	St. XXXVI.

TABLE OF ALTITUDES DETERMINED BETWEEN PAU-TING-FU, CHÏ-LI, AND T'AI-YÜAN-FU, SHAN-SI, BY GRAPHIC TRIANGULATION AND VERTICAL ANGLES.—Continued.

Description of point of which the altitude was determined.	Adjusted altitude.		Elevation obtained.	Distance, miles.	By foresight from or backsight to stations named below.
	Meters.	Feet.			
Station XXXVI.—Lat. 39° 0′ 12″, Long. 113° 37′ 44″. Atlas sheet D 1.	2203	7228	7226 7195	6.76	St. XXXIII.
			7230	1.08	St. XXXIV.
			7223	.66	St. XXXV.
Station XXXVII.—Lat. 38° 58′ 46″, Long. 113° 30′ 46″. Atlas sheet D 1.	2500	8204	8195 8203	10.80	St. XXIX.
			8217	13.31	St. XXXI.
			8234 8211	6.38	St. XXXII.
			8189 8206	4.71	St. XXXIII.
Station XXXVIII.—Lat. 38° 57′ 59″, Long. 113° 29′ 55″. Atlas sheet C 1.	2287	7502	7515	6.90	St. XXXII.
			7489	4.38	St. XXXIII.
Station XXXIX.—Lat. 38° 55′ 10″, Long. 113° 26′ 50″. Atlas sheet C 1.	1931	6334	6338 6323	5.61	St. XXXIII.
			6332	5.42	St. XXXVII.
			6346	4.24	St. XXXVIII.
Station XL.—Lat. 38° 54′ 2″, Long. 113° 27′ 53″. Atlas sheet C 1.	1295	4249	4233	6.04	St. XXXVII.
			4261	4.91	St. XXXVIII.
			4251 4250	1.58	St. XXXIX.
Station XLI.—Lat. 38° 51′ 40″, Long. 113° 26′ 19″. Atlas sheet C 1.	1353	4439	4437	7.24	St. XXXIII.
			4452	7.95	St. XXXVIII.
			4435 4423	4.06	St. XXXIX.
Station XLII.—Lat. 38° 51′ 16″, Long. 113° 24′ 26″. Atlas sheet C 1.	1437	4716	4716 4715	1.74	St. XLI.
Station XLIII.—Lat. 38° 47′ 53″, Long. 113° 20′ 16″. Atlas sheet C 1.	1667	5470	5477	14.43	St. XXXIII.
			5450	7.22	St. XLI.
Station XLIV.—Lat. 38° 49′ 5″, Long. 113° 21′ 5″. Atlas sheet C 1.	1349	4426	4421	12.83	St. XXXIII.
			4409	14.15	St. XXXVIII.
			4458	5.09	St. XLI.
			4416	3.96	St. XLII.
			4426	1.90	St. XLIII.
Station XLV.—Lat. 38° 45′ 14″, Long. 113° 25′ 50″. Atlas sheet C 1.	1730	5677	5678	13.07	St. XXXIII.
			5673	11.46	St. XXXIX.
			5686	7.39	St. XLI.
			5644 5668	7.04	St. XLII.
			5676 5682	5.62	St. XLIII.
Station XLVI.—Lat. 38° 48′ 24″, Long. 113° 31′ 38″. Atlas sheet D 1.	2130	6988	6978	7.84	St. XXXI.
			6983	7.75	St. XXXIII.
			7003	11.88	St. XXXVII.
Station XLVII.—Lat. 38° 49′ 48″, Long. 113° 31′ 7″. Atlas sheet D 1.	2047	6717	6726	8.13	St. XXXI.
			6717	6.30	St. XXXIII.
			6709	1.66	St. XLVI.
Station XLVIII.—Lat. 38° 46′ 18″, Long. 113° 24′ 10″. Atlas sheet C 1.	1422	4664	4660	3.77	St. XLIII.
			4669 4664	1.89	St. XLV.
Station XLIX.—Lat. 38° 42′ 57″, Long. 113° 19′ 2″. Atlas sheet C 1.	1443	4735	4746 4713	5.46	St. XLIII.
			4727 4738	6.72	St. XLV.
			4750	6.08	St. XLVIII.
Station L.—Lat. 38° 44′ 12″, Long. 113° 19′ 15″. Atlas sheet C 1.	1417	4649	4638	4.01	St. XLIII.
			4643	6.07	St. XLV.
			4660	5.09	St. XLVIII.
			4649	1.46	St. XLIX.

Table of Altitudes Determined between Pau-ting-fu, Chï-li, and T'ai-yüan-fu, Shan-si, by Graphic Triangulation and Vertical Angles.—Continued.

Description of point of which the altitude was determined.	Adjusted altitude.		Elevation obtained.	Distance, miles.	By foresight from or backsight to stations named below.
	Meters.	Feet.			
Station LI.—Lat. 38° 37′ 38″, Long. 113° 21′ 26″. Atlas sheet C I.	1484	4868	4866	11.44	St. XLIII.
			4865	6.43	St. XLIX.
			4873	7.75	St. L
Station LII.—Lat. 38° 39′ 56″, Long. 113° 27′ 38″. Atlas sheet C I.	1443	4735	4724	10.88	St XLIII.
			4724	6.28	St. XLV.
			4757	6.19	St. LI.
Station LIII.—Lat. 38° 40′ 22″, Long. 113° 26′ 4″. Atlas sheet C I.	1294	4247	4244	5.70	St. XLV.
			4249 4247	1.41	St. LII.
Station LV.—Lat. 38° 33′ 56″, Long. 113° 23′ 4″. Atlas sheet C II.	1455	4773	4762	4.49	St. LI.
			4784	7.81	St. LIII.
Station LVI.—Lat. 38° 34′ 35″, Long. 113° 23′ 16″. Atlas sheet C II.	1410	4628	4616	3.90	St. LI.
			4630 4640	.72	St. LV.
Station LVII.—Lat. 38° 31′ 52″, Long. 113° 17′ 44″. Atlas sheet C II.	1553	5096	5083 5087	7.43	St. LI
			5117	5.38	St. LV.
Station LVIII.—Lat. 38° 32′ 4″, Long. 113° 17′.42″. Atlas sheet C II.	1547	5076	5075 5077	.26	St. LVII.
Station LIX.—Lat. 38° 32′ 56″, Long. 113° 18′ 49″. Atlas sheet C II.	1464	4804	4790	5.90	St. LI.
			4820	4.01	St. LV
			4801	4.41	St. LVI
Station LX.—Lat. 38° 37′ 17″, Long. 113° 19′ 11″. Atlas sheet C I.	1808	5933	5933 5919	11.82	St. XLIII.
			5920	10.97	St. XLV.
			5946 5932	6.46	St. XLIX.
			5946	7.91	St. L.
Station LXI.—Lat. 38° 40′ 42″, Long. 113° 18′ 14″. Atlas sheet C I.	1229	4033	4024	2.63	St. XLIX
			4043	4.54	St. LI.
			4031	4.02	St. LX.
Station LXII.—Lat. 38° 40′ 42″, Long. 113° 18′ 6″. Atlas sheet C I.	1227	4025	4015	2.65	St. XLIX.
			4043	4.62	St. LI.
			4018	4.06	St. LX.
Station LXIII.—Lat. 38° 42′ 0″, Long. 113° 11′ 46″. Atlas sheet C I.	1520	4986	4992	10.05	St. XLIII.
			4970 4963	13.26	St. XLV.
			5012 4989	6.66	St. XLIX.
			4973 4993	7.24	St. L.
			5012	8.62	St. LX.
Station LXIV.—Lat. 38° 35′ 17″, Long. 113° 8′ 46″. Atlas sheet C I.	1253	4112	4145 4128	12.77	St. XLIX.
			4095	9.72	St. LX.
			4089 4108	8.16	St. LXIII.
Station LXV.—Lat. 38° 40′ 18″, Long. 113° 5′ 23″. Atlas sheet C I.	1308	4293	4347	12.90	St. LX.
			4279 4304	6.03	St. LXIII.
			4271 4293	6.49	St. LXIV.
Station LXVI.—Lat. 38° 31′ 24″, Long. 113° 6′ 7″. Atlas sheet C II.	1167	3828	3863	13.59	St. LX.
			3855	13.13	St. LXIII.
			3816 3784	5.02	St. LXIV.
			3823	10.19	St. LXV.

TABLE OF ALTITUDES DETERMINED BETWEEN PAU-TING-FU, CHĬ-LI, AND T'AI-YÜAN-FU, SHAN-SI, BY GRAPHIC TRIANGULATION AND VERTICAL ANGLES.—Continued.

Description of point of which the altitude was determined.	Adjusted altitude.		Elevation obtained.	Distance, miles.	By foresight from or backsight to stations named below.
	Meters.	Feet.			
Station LXVII.—Lat. 38° 31′ 50″, Long. 113° 4′ 23″. Atlas sheet C II.	999	3277	3265	5.54	St. LXIV.
			3285 3281	1.62	St. LXVI.
Station LXVIII.—Lat. 38° 31′ 44″, Long. 113° 3′ 24″. Atlas sheet C II.	838	2751	2732	6.29	St. LXIV.
			2751	9.94	St. LXV.
			2761	2.50	St. LXVI.
			2758	.93	St. LXVII.
Station LXXI.—Lat. 38° 21′ 3″, Long. 112° 59′ 1″. Atlas sheet B II.	2114	6937	6955	26.64	St. LXIII.
			6964	18.54	St. LXIV.
			6973	22.81	St. LXV.
			6927 6960	13.15	St. LXVI.
			6920 6907	13.33	St. LXVII.
			6927	8.67	St. LXVIII.
Station LXXV.—Lat. 38° 19′ 57″, Long. 112° 41′ 18″. Atlas sheet B II.	1180	3872	3869 3874	16.10	St. LXXI.
Station LXXVI.—Lat. 38° 19′ 18″, Long. 112° 41′ 15″. Atlas sheet B II.	1137	3731	3740	16.22	St. LXXI.
			3725 3729	8.60	St. LXXV.
Station LXXVII.—Lat. 38° 15′ 22″, Long. 112° 49′ 23″. Atlas sheet B II.	2003	6573	6567	9.00	St. LXXV.
			6569 6594	8.60	St. LXXVI.
Station LXXVIII.—Compound of temple east of Han-yang.—Lat. 38° 19′ 50″, Long. 112° 46′ 18″. Atlas sheet B II.	838	2749	2754	11.59	St. LXXI.
			2750 2732	4.55	St. LXXV.
			2739	4.63	St. LXXVI.
			2778 2738	5.80	St. LXXVII.
Station LXXX.—Lat. 38° 13′ 47″, Long. 112° 41′ 29″. Atlas sheet B II.	1466	4811	4821	17.95	St. LXXI.
			4812 4793	7.17	St. LXXV.
			4816 4809	6.37	St. LXXVI.
			4817	7.32	St. LXXVII.
Station LXXXI.—Lat. 38° 13′ 54″, Long. 112° 42′ 22″. Atlas sheet B II.	1420	4658	4662 4652	7.11	St. LXXV.
			4655	6.32	St. LXXVI.
			4671	6.55	St. LXXVII.
			4657 4649	.79	St. LXXX.
Station LXXXII.—Lat. 38° 9′ 18″, Long. 112° 43′ 38″. Atlas sheet B II.	1011	3318	3330 3297	5.52	St. LXXX.
			3313 3321	5.42	St. LXXXI.
Station LXXXIII.—Lat. 38° 6′ 57″, Long. 112° 41′ 32″. Atlas sheet B II.	1085	3560	3565	12.03	St. LXXVII.
			3567 3535	7.84	St. LXXX.
			3540 3584	8.01	St. LXXXI.
			3571 3517	3.38	St. LXXXII.
Station LXXXIV.—Lat. 38° 6′ 31″, Long. 112° 36′ 40″. Atlas sheet B II.	1435	4709	4715	15 52	St. LXXVII.
			4737 4691	9.71	St. LXXX.
			4790 4720	10.20	St. LXXXI.
			4697 4721	7.24	St. LXXXII.
			4711 4700	4.36	St. LXXXIII.

Table of Altitudes Determined between Pau-ting-fu, Chï-li, and T'ai-yüan-fu, Shan-si, by Graphic Triangulation and Vertical Angles.—Continued.

Description of point of which the altitude was determined.	Adjusted altitude.		Elevation obtained.	Distance, miles.	By foresight from or backsight to stations named below.
	Meters	Feet.			
Station LXXXV.—Lat. 38° 3′ 48″, Long. 112° 37′ 18″. Atlas sheet B III.	1274	4179	4188 } 4168 }	12.05	St. LXXX.
			4160 } 4203 }	12.43	St. LXXXI.
			4170 } 4182 }	5.23	St. LXXXIII.
			4183 } 4175 }	2.74	St. LXXXIV.
Station LXXXVI.—Lat. 38° 59′ 35″, Long. 112° 25′ 48″. Atlas sheet A III.	1482	4861	4843	21.59	St. LXXX.
			4891	22.18	St. LXXXI.
			4865 } 4822 }	12.47	St. LXXXIV.
			4822 } 4875 }	11.48	St. LXXXV.
Station LXXXVII.—Point on wall of city T'ai-yüan-fu. Elevations made from combining a series of shots to different points of the wall and reducing all to this one station. Atlas sheet B III.	843	2767	2785		
			2731		
			2756		
			2754		
			2778		
			2750		
			2743		
			2786		
			2807		
			2804		
			2760		
			2731		
			2786		
T'ai-yüan-fu.—Top of wall at N. gate. Atlas sheet B III.	824	2702			
Terrace at the base of the Pai-t'a (White Pagoda) in town of Wu-t'ai-shan.—Lat. 39° 0′ 7″, Long. 113° 36′ 27″. Atlas sheet D I.	1715	5627			
Peï-t'ai (North T'ai).—Lat. 39° 4′ 25″, Long. 113° 35′ 52″. Atlas sheet D I.	3061	10042	10074	8.89	St. XXXII.
			10039	10.87	St. XXXIII.
			10028	7.55	St. XXXVII.
Tung-t'ai (East T'ai).—Lat. 39° 2′ 6″, Long. 113° 40′ 46″. Atlas sheet D I.	2799	9182	9205	6.64	St. XXXII.
			9173	10.59	St. XXXIII.
			9188	3.90	St. XXXVI.
			9160	9.74	St. XXXVII.
Si-t'ai (West T'ai).—Lat. 39° 1′ 53″, Long. 113° 30′ 28″. Atlas sheet D I.	2781	9123	9135	8.46	St. XXXII.
			9083	8.14	St. XXXIII.
			9124	3.58	St. XXXVII.
Chung-t'ai (Middle T'ai).—Lat. 39° 2′ 24″, Long. 113° 32′ 52″. Atlas sheet D I.	2896	9501	9468	15.85	St. XXXI.
			9490	8.39	St. XXXIII.
			9530	5.13	St. XXXIV.
			9516	4.58	St. XXXVII.
Hin-chóu.—Top of north corner of wall. Lat. 38° 24′ 0″, Long. 112° 46′ 1″. Atlas sheet B II.	821	2693	2681	12.23	St. LXXI.
			2692	6.32	St. LXXV.
			2705	6.95	St. LXXVI.
Wu-t'ai-hién.—Top of S. E. corner of wall. Lat. 38° 43′ 0″, Long. 112° 16′ 31″. Atlas sheet C I.	1059	3474	3477	2.25	St. XLIX.
			3472	2.81	St. L.

Elevations of Plane-Table Stations and Prominent Points from Heï-shui-k'ou to Yang-tzï River determined by Vertical Angles in Connection with Surveys by Graphic Triangulation and Stadia; based on Adjustment of Barometer Readings kept throughout the Trip and compared with Barometric Records at the Jesuit Observatory at Shanghai.

Station.	Elevation.		Description.
	Meters.	Feet.	
Heï-shui-k'ou	452	1482	Atlas Sheet a1.—Lat. 34° 3′ 44″, Long. 108° 16′ 52″
LXXXVIII	983	3225	Atlas Sheet a1.— " 34° 2′ 39″, " 108° 16′ 54″
LXXXIX	993	3257	Atlas Sheet a1.— " 34° 2′ 38″, " 108° 14′ 30″
XC	1159	3804	Atlas Sheet a1.— " 34° 0′ 8″, " 108° 15′ 6″
XCI	1534	5032	Atlas Sheet a2.— " 33° 58′ 30″, " 108° 14′ 56″
XCII	1670	5480	Atlas Sheet a2.— " 33° 58′ 21″, " 108° 15′ 55″
XCIII	1770	5809	Atlas Sheet a2.— " 33° 56′ 32″, " 108° 14′ 34″
XCIV	1933	6343	Atlas Sheet a2.— " 33° 55′ 30″, " 108° 14′ 36″
XCV	2072	6798	Atlas Sheet a2.— " 33° 55′ 41″, " 108° 15′ 32″
XCVI	2082	6831	Atlas Sheet a2.— " 33° 54′ 3″, " 108° 15′ 44″
XCVII	1771	5810	Atlas Sheet a2.— " 33° 53′ 24″, " 108° 15′ 39″
XCIX	2237	7340	Atlas Sheet a2.— " 33° 47′ 33″, " 108° 13′ 52″
C	2249	7377	Atlas Sheet a2.— " 33° 47′ 10″, " 108° 17′ 5″
Wön-kung-miau (Pass)	2341	7680	Atlas Sheet a2.— " 33° 43′ 22″, " 108° 16′ 16″
Shï-ts'üan-hién	366	1202	Atlas Sheet a3.— " 33° 1′ 30″, " 108° 18′ 15″ Top of west gate.
Hing-an-fu	229	750	Atlas Sheet c4.— " 32° 41′ 58″, " 109° 2′ 43″ Top of south gate.
Ki-sin-ling (Pass)	1650	5412	Atlas Sheet d6.— " 31° 43′ 39″, " 109° 54′ 45″
Yang-tzï River	64	210	Atlas Sheet a7.— " 31° 3′ 56″, " 109° 54′ 45″ Water at Wu-shan-hién on June 6, 1904. River was at a low stage.

Traverse by Boat Down the Han River.

From station.*	Course.	Length of course in miles.	Time from Shï-ts'üan-hién.	Rate of river, miles per hour.	To station distant from Shï-ts'üan-hién.	Remarks.
	Degrees.		*h. m. s.*		*Miles.*	
Shï-ts'üan-hién.	S 70 E	1.50	13 30	6.6	1.5	Small rapids .75 mile below Shï-ts'üan-hién
1.5	N 12 E	.85	22 50	5.5	2.35	
2.35	S 40 E	.82	31 50	5.5	3.17	
3.17	S 7 W	.41	36 20	5.5	3.58	
3.58	S 25 W	.52	41 10	6.5	4.10	Rapids commence—1 minute to run them.
4.10	S 25 W	.51	46 25	6	4.61	
4.61	S 21 E	.37	49 10	6	4.98	Rapids—1 minute to run them.
4.98	S 21 E	.84	58 30	6	5.82	
5.82	S 28 E	.47	1 3 10	6	6.29	
6.29	S 52 E	.80	1 11 10	4.5	7.09	Lién-hua-shï.
7.09	S 52 E	.55	1 21 12	4.5	7.64	Through narrow canyon.
7.64	W	.67	1 30 10	4.5	8.31	
8.31	S 45 W	.37	1 36 25	3.5	8.68	Rapids.
8.68	S 30 W	.57	1 46 10	3.5	9.25	
9.25	S 50 W	.33	1 54 10	2.5	9.58	
9.58	S 30 W	.86	2 20 10	2	10.44	
10.44	S 25 W	.67	2 36 10		11.11	Yü-fang-p'ing—shoals at this point.
11.11	S 65 E	1.17	2 53 40	4	12.28	
12.28	S 15 E	.30	2 58 30		12.58	
12.58	S 30 W	1.25	3 13 30	5	13.83	
13.83	S	.57	3 26 10		14.40	

*Stations are designated by the distance in miles from Shï-ts'üan-hién.

TRAVERSE BY BOAT DOWN THE HAN RIVER.—Continued.

From station.*	Course.	Length of course in miles.	Time from Shï-ts'üan-hién.	Rate of river, miles per hour.	To station distant from Shï-ts'üan-hién.	Remarks.
	Degrees.		*h. m. s.*		*Miles.*	
14.40	S 28 W	1.97	4 1 40	3.8	16.37	
16.37	S 15 E	.40	4 9 20		16.77	
16.77	S 65 E	.19	4 14 00		16.98	
16.98	N 65 E	1.17	4 30 30	4	18.15	
18.15	N	1.50	4 48 30	5	19.55	
19.55	S 45 E	.15	4 55 00	6	20.30	
20.30	S 83 E	.42	5 00 00	5	20.72	
20.72	S 60 E	1.45	5 15 50	5.5	22.17	
22.17	S 20 E	.54	5 24 00	4	22.71	
22.71	S 34 W	.69	5 34 20	4	23.40	
23.40	S 18 W	1.78	5 55 40	5	25.18	Han-yang-p'ing—Called 121 li from Shï-ts'üan-hién.
25.18	S 26 E	1.07	6 40 30	5	26.25	
26.25	S 55 E	1.27	6 59 30	4	27.52	Fu-shui-ho—rapids.
27.52	S 55 E	.23	7 3 00	4	27.75	
27.75	S	.40	7 11 00	3	28.15	
28.15	S 28 E	.74	7 23 40	3.5	28.89	
28.89	S 48 E	.74	7 46 00	2	29.63	
29.63	S 70 E	.33	7 52 30	3	29.96	
29.96	E	1.52	8 21 20	3.25	31.48	Süé-hua.
31.48	S	.42	8 33 20		31.90	
31.90	S 70 E	1.78	8 56 5	4.7	33.68	
33.68	S 50 E	.67	9 4 35	4.7	34.35	Large creek from south
34.35	N 80 E	.76	9 14 10	4.7	35.11	
35.11	S 80 E	1.31	9 29 50	5	36.42	
36.42	N 50 E	1.19	9 40 00	7	37.61	
37.61	S 10 E	.43	9 44 20	6	38.04	
38.04	S 30 W	.32	9 47 30	6	38.36	Han-wang-ch'öng.
38.36	S 30 W	1.00	9 59 30	5	39.36	
39.36	N 60 W	.49	10 4 15		39.85	
39.85	S 75 W	.40	10 7 30	1.4	40.25	Island on west, channel narrow and dangerous, 1½ miles.
40.25	S 60 E	.45	10 14 15	4	40.70	
40.70	S 20 E	.38	10 18 50		41.08	
41.08	S 80 E	.65	10 27 30	4.5	41.73	
41.73	S 40 W	.52	10 34 15	4	42.25	
42.25	S 10 E	.53	10 38 20	4.5	42.78	
42.78	S	.32	10 47 30	4.5	43.10	
43.10	S	.53	10 53 45	5	43.63	
43.63	S 30 E	1.56	11 19 00	3.7	45.19	Creek from west.
45.19	E	.89	11 32 20	4	46.08	Creek from east.
46.08	S 65 E	1.18	11 46 30	5	47.26	
47.26	S 20 E	.31	11 51 15	4	47.57	
47.57	S 5 E	1.88	12 11 40	5.5	49.45	
49.45	S 85 E	.23	12 15 30		49.68	
49.68	N 64 E	1.20	12 35 30	3.6	50.88	
50.88	S 40 E	.25	12 42 30		51.13	
51.13	S 40 W	1.08	13 00 30	3.6	52.21	
52.21	S 80 W	.73	13 13 00	3.5	52.94	
52.94	S 40 W	.53	13 29 00	3.2	53.47	Huan-ku-t'an.
53.47	S 15 E	.35	13 34 40		53.82	Bad rapids.
53.82	S 50 E	.96	13 41 50	8	54.78	
54.78	S 40 E	.78	13 47 40	8	55.56	
55.56	S 45 E	.31	13 51 30		55.87	
55.87	S 72 E	1.04	14 6 20	4.2	56.91	
56.91	S 60 E	.10	14 8 30		57.01	
57.01	S 55 E	1.63	14 28 00	5	58.64	
58.64	S 10 E	.43	14 34 30	4	59.07	
59.07	S 10 W	.86	14 47 30	4	59.93	

*Stations are designated by the distance in miles from Shï-ts'üan-hién

TRAVERSE BY BOAT DOWN THE HAN RIVER.—Continued.

From station.*	Course.	Length of course in miles.	Time from Shï-ts'üan-hién.	Rate of river, miles per hour.	To station distant from Shï-ts'üan-hién.	Remarks.
	Degrees.		*h. m. s.*		*Miles.*	
59.93	S 25 E	.40	14 56 10		60.33	
60.33	S 65 E	.44	15 3 40	3.5	60.77	
60.77	S 50 E	.78	15 17 00	3.5	61.55	Creek from east.
61.55	S 20 E	.28	15 22 30	3	61.83	Tzï-yang-hién.
61.83	S 20 E	.20	15 29 30		62.03	
62.03	E	.20	15 34 30		62.23	
62.23	N 4 E	.75	15 44 30		62.98	Large creek from west.
62.98	S 60 E	.75	15 54 40	4.5	63.73	
63.73	S 48 E	.35	15 58 30		64.08	
64.08	S 70 E	1.29	16 13 10	3.25	65.37	Small stream from west.
65.37	S 40 E	.46	16 21 00	3.5	65.83	
65.83	S 62 E	.83	16 34 20	3.25	66.66	
66.66	S 38 E	.37	16 41 40	3	67.03	
67.03	S 10 E	.46	16 49 30	3.5	67.49	
67.49	S 18 E	.34	16 53 15		67.83	Bad rapids commence here.
67.83	S 85 E	.10	16 56 15		67.93	Tung-ho. Took native pilot here.
67.93	N 70 E	.19	17 6 10		68.10	Bad rapids below town, dangerous rocks.
68.10	N	1.26	17 13 45	6	69.38	
69.38	N 15 E	.71	17 24 30	4	70.09	
70.09	E	.11	17 28 35		70.20	
70.20	S 75 E	.49	17 37 00	3.5	70.69	
70.69	N 82 E	.76	17 43 15	8	71.45	
71.45	N 82 E	1.19	17 57 30	5	72.64	
72.64	N 82 E	.10	18 3 15		72.74	
72.74	S 60 E	.75	18 8 00	10	73.49	Swift rapids.
73.49	N 85 E	.56	18 14 45	5	74.05	
74.05	S 50 E	.39	18 22 10	3	74.44	Ta-tau-ho.
74.44	S 70 E	.57	18 26 25	8	75.01	
75.01	N 20 E	.10	18 28 50		75.11	
75.11	S 45 E	.30	18 35 45		75.41	
75.41	N 30 E	.51	18 43 10	4	75.92	
75.92	N 60 E	.43	18 55 25	2.7	76.35	
76.35	N 85 E	.45	19 2 00	4	76.80	
76.80	E	.41	19 14 15	2	77.21	Coal mines.
77.21	N 70 E	.90	19 22 00	7	78.11	Siau-tau-ho.
78.11	N 40 E	.50	19 28 00	5	78.61	
78.61	N 28 E	.30	19 33 00	7	78.91	
78.91	N 25 E	.76	19 48 15	3	79.67	
79.67	N 50 E	.63	19 57 45	4	80.30	
80.30	N 30 E	.30	20 1 5		80.60	Rapids here.
80.60	N 60 E	.40	20 5 45		81.00	
81.00	N 15 E	.68	20 14 15	4.3	81.68	
81.68	N 30 W	.40	20 20 15		82.08	
82.08	W	.44	20 27 45	3.5	82.52	
82.52	N 15 E	.35	20 32 45		82.87	
82.87	N 30 E	.54	20 41 10	3.5	83.41	
83.41	N 10 E	.42	20 47 30	4	83.83	
83.83	N 70 W	.39	20 54 10	3.5	84.22	Liu-shui-tién.
84.22	N 20 E	.10	20 58 00		84.32	
84.32	N 88 E	.34	21 6 00	2.5	84.66	
84.66	S 50 E	.25	21 12 00	2.5	84.91	
84.91	E	.25	21 17 00	3	85.16	
85.16	N 85 E	.33	21 25 00	2.5	85.49	
85.49	N 5 E	.45	21 34 00	3	85.94	
85.94	N 25 E	.64	21 39 30	7	86.58	Rapids.
86.58	N 70 E	.12	21 42 00		86.70	Bad rocks.
86.70	S 60 E	.35	21 47 00		87.05	

*Stations are designated by the distance in miles from Shï-ts'üan-hién.

TRAVERSE BY BOAT DOWN THE HAN RIVER.—Continued.

From station.*	Course.	Length of course in miles.	Time from Shĭ-ts'üan-hién.	Rate of river, miles per hour.	To station distant from Shĭ-ts'üan-hién.	Remarks.
	Degrees.		*h. m. s.*		*Miles.*	
87.05	S 25 E	.30	21 50 00		87.35	
87.35	S	.37	21 55 30	4	87.72	Small creek from west.
87.72	S 40 E	.28	22 1 00	3	88.00	
88.00	N 60 E	.15	22 2 30	3.5	88.15	
88.15	N 32 W	.10	22 4 30		88.25	
88.25	N 5 E	.22	22 9 10	3.2	88.47	
88.47	E	.20	22 13 00		88.67	
88.67	S 50 E	.34	22 22 00		89.01	
89.01	S 12 E	.59	22 35 30	2.7	89.60	Rapids.
89.60	S 20 W	.35	22 38 30	7	89.95	
89.95	S 20 W	.39	22 43 45	4.5	90.34	
90.34	S 80 E	.75	22 55 00	4	91.09	
91.09	N 80 E	.12	22 59 50		91.21	
91.21	N 40 E	.30	23 5 50		91.51	
91.51	N 80 E	.75	23 14 50	3.2	92.26	Lan-ho-k'ou.
92.26	N 50 E	.10	23 18 40		92.36	
92.36	N 10 W	.36	23 24 50		92.72	
92.72	N 60 W	.20	23 26 00	10	92.92	Bad rocks here.
92.92	N 62 W	.27	23 31 20	3	93.19	
93.19	N 30 E	.12	23 33 20		93.31	
93.31	S 75 E	.33	23 39 50	3	93.64	
93.64	E	.35	23 45 30	3.7	93.99	
93.99	N 52 E	.47	23 53 30	3.5	94.46	
94.46	E	.10	23 55 05		94.56	
94.56	E	1.12	24 13 05	3.9	95.68	Huo-shĭ-yen.
95.68	N 60 E	.10	24 26 35		95.78	
95.78	N 10 E	.10	24 29 10		95.88	
95.88	N 32 W	.41	24 37 10	3	96.29	
96.29	N 7 E	.20	24 41 30		96.49	
96.49	N 10 E	1.13	25 8 35	2.5	97.62	
97.62	N 58 E	.38	25 19 00	2.1	98.00	
98.00	N 40 E	.82	25 36 30	2.4	98.82	
98.82	N 72 E	1.64	26 15 50	2.5	100.46	
100.46	E	1.41	26 44 00	3	101.87	
101.87	N 43 E	.26	26 50 20	2.5	102.13	Large creek from south.
102.13	N 43 E	1.00	27 14 10	2.5	103.13	Yü-ho.
103.13	N	.46	27 28 05	2	103.59	
103.59	N 30 E	.99	27 57 50	2	104.48	At northwest corner Hing-an-fu.

*Stations are designated by the distance in miles from Shĭ-ts'üan-hién.

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RESEARCH IN CHINA

IN THREE VOLUMES AND ATLAS

VOLUME ONE IN TWO PARTS

PART ONE

DESCRIPTIVE TOPOGRAPHY AND GEOLOGY

by

Bailey Willis, Eliot Blackwelder, and R. H. Sargent

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